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LOW SPEED AERODYNAMIC CHARACTERISTICS OF AN A-4 AIRCRAFT WITH AN AIR CUSHION LANDING SYSTEM

David G. Lee, et al

Naval Ship Research and Development Center

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by

David G. Lee and H. Dulany Davidson, Jr.

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13. ABSTRACT

The effect of a twin trunk air cushion landing gear system on the stability and control of an A-4 type aircraft was evaluated through an exploratory wind tunnel program. The active air cushion in ground effect conditions was found to reduce both drag and the static margin and markedly degrade the directional stability characteristics of the 22 percent scale wind tunnel model. However, the modified aircraft retains adequate longitudinal stability and both the flaps and stabilizer controls are effective and adequate for trimming the aircraft.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
A-4						
Air cushion landing gear						
Directional stability						
Drag						
Lateral stability						
Lift						
Longitudinal stability						
Pitching moment						
Stability and control						
Subsonic						
Yaw						

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This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Naval Air Systems Command.

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February 1973 Evaluation Report AL-98

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

The effect of a twin trunk air cushion landing gear system on the stability and control of an A-4 type aircraft was evaluated through an exploratory wind tunnel program. The active air cushion in ground effect conditions was found to reduce both drag and the static margin and markedly degrade the directional stability characteristics of the 22 percent scale wind tunnel model. However, the modified aircraft retains adequate longitudinal stability and both the flaps and stabilizer controls are effective and adequate for trimming the aircraft.

ADMINISTRATIVE INFORMATION

The data in this report was produced as part of the Surface Effects Take-Off and Landing System (SETOLS) Program at the Naval Ship Research and Development Center. This program is under the direction of the Naval Air Systems Command (03P) and is sponsored by the Advanced Research Projects Agency of the Department of Defense.

INTRODUCTION

The concept of an air cushion landing gear (ACLG) system utilizes technology developed for ground effect or air cushion vehicles. Basically a cushion of air is maintained in a suitable housing or trunk beneath the aircraft fuselage area. During the take off and landing phase, this "bubble" supports the weight of the aircraft and hence replaces the conventional wheel landing gear system. Such an ACLG equipped high performance aircraft offers the prospect of increased operational flexibility for tactical Navy aircraft. This is achieved through the capability for operations from water and/or unprepared terrain. Navy aircraft would not be constrained to operations from carriers or other forward prepared airfields.

The Naval Ship Research and Development Center (NSRDC) under the sponsorship of the Advanced Research Projects Agency has undertaken a program to determine the feasibility and best approach to the development of an ACLG system for high performance Navy aircraft. Under the direction of the Naval Air Systems Command, NSRDC initiated the Surface Effects Take-off and Landing System (SETOLS) Program. Results of earlier studies by industrial contractors analyzing the feasibility of incorporating a SETOLS into an F-8 or A-4 test bed aircraft indicate the A-4 configuration as most likely candidate; the twin trunk configuration of the A-4 exhibiting certain advantages in terms of stability in ground effect and ease of interfacing with the aircraft structure. All proposed aircraft and trunk configurations were evaluated by NSRDC in exploratory wind tunnel programs to obtain stability and control characteristics using 10 percent scale F-8 and A-4 models with inactive air cushion systems (see References 1 and 2).

One of the objectives in the current phase of the Navy SETOLS Program is to further define the aerodynamic characteristics of the A-4 twin trunk concept during takeoff and landing with both an active air trunk system and ground effect simulation with a moving ground belt. This report presents the results of an exploratory wind tunnel program designed to meet that objective.

NOMENCLATURE

The results presented in this report are referred to the stability system of axes which has the origin at the model center of gravity. This position is located at 25 percent of the wing's mean aerodynamic chord, and for the A-4 model's coordinate system is at F.S. = 51.827 and 3.96 below the F.R.L. The F.R.L. coincides with the model C.L. for this aircraft.

b	Wing span (6.050 ft)
$\bar{c}$	Wing mean aerodynamic chord (2.376 ft)
h	Height $\bar{c}$ above ground
q	Dynamic pressure, lbs/ft^2
s	Wing area (12.584 ft^2)
C_D	Drag coefficient; $\frac{drag}{qs}$
C_L	Lift coefficient; $\frac{lift}{qs}$
C_ℓ	Rolling moment coefficient; $\frac{rolling\ moment}{qsb}$
C_m	Pitching moment coefficient; $\frac{pitching\ moment}{qs\bar{c}}$
C_n	Yawing moment coefficient; $\frac{yawing\ moment}{qsb}$
C_y	Side force coefficient; $\frac{side\ force}{qs}$
α	Angle of attack, degree
β	Angle of sideslip, degree
δ_f	Flap deflection, degree
δ_h	Horizontal stabilizer deflection, degree
A4G	A-4 with conventional landing gear deployed
A4P	A-4 with ACLG system installed and conventional landing gear deployed
A4PB	A-4 with ACLG system installed and deployed
A4PBV	A4PB configuration with added vertical stabilizers

APPARATUS

This exploratory investigation was conducted during November 1972 at the Vought Aeronautics Division (VAD), LTV Aerospace Corporation low speed wind tunnel. The tunnel is a horizontal single-return, tandem test section, closed-circuit facility. The program was conducted in the rectangular 15 x 20-foot V/STOL test section. This section incorporates a moving belt ground plane which is flush mounted in the floor. Additional information on this facility can be obtained in Reference 3.

The wind tunnel model was a Navy TA-4F version of the A-4 aircraft. This was an existing model modified to accept a twin trunk air cushion system. It is a 22 percent scale model constructed of wood over a steel core with adjustable wing slats and flaps in addition to an adjustable horizontal stabilizer. Additional model parts allow for installation of speed brakes and landing gear assembly to the basic aircraft. The model has flow through inlets which were closed with fairings for this program. General dimensions of the TA-4F aircraft are shown in Figure 1. The podded, twin trunk ACLG system was fabricated from wood with a fiberglas shell simulating the air bag in an inflated condition. The hole pattern in each air bag consisted of equally spaced 0.25 inch diameter holes. A total of 128 holes were staggered in 3 rows on the surface of the air bag; the outer two rows being equidistant about the bag-ground contact line. General dimensions of the ACLG system model are shown in Figure 2 with more detailed information on the A-4 twin trunk concept contained in Reference 4. Auxiliary air was supplied to the ACLG system on the model via a combination of flexible and rigid hoses routed along the sting support and assembly system to plenum chambers in the trunk system. The air then passed into the bag cavity and was exhausted to free stream. Figures 3 through 8 present a series of installation photographs showing the wind tunnel model in various configurations of interest.

WIND TUNNEL PROGRAM

Data from the wind tunnel program in the form of raw counts from the VTB-6 internal strain-gage balance was converted to six component force and moment data (lift, drag, pitching moment, side force, yawing and rolling moment) and then reduced to coefficient form. Corrections to the data were made for the effects of model static weight tares, air line pressure tares, tunnel blockage and compressibility. In addition to model force data, transducers were installed in the ACLG system to provide air cushion pressure, trunk pressure and trunk temperature. A previous program at LTV listed as Reference 5 was similar in scope and objective, consequently the same data reduction technique and instrumentation was utilized in the A-4 SETOLS program.

There were 3 baseline configurations in the wind tunnel program: (1) Basic A-4 in conventional landing mode, (2) A-4 with ACLG system installed and (3) A-4 with ACLG system installed and deployed. The basic A-4 landing configuration has the leading edge slats, trailing edge flaps, speed brakes and a conventional wheel landing gear deployed (see Figure 5). When the ACLG system is carried on the A-4, it is housed in two pods on pylons mounted under the wing (see Figure 6). In the twin trunk concept for the A-4 aircraft, the conventional wheel landing gear system will be deployable when the ACLG system is installed. The third configuration is the A-4 with the ACLG system installed and the air bag deployed, i.e., inflated (see Figure 4). Limited data for the A-4 in a "clean" configuration (Figure 3) and with auxiliary vertical stabilizers in the ACLG mode (Figure 8) was taken for comparative purposes. These vertical stabilizers had the following model scale dimensions: 50 degree leading edge sweep from the vertical, tip to tip span of 11.88 inches, and root chord of 7.92 inches.

The wind tunnel was operated at a constant dynamic pressure of 6.4 pounds per square foot. Whenever the model was in ground effect, the moving ground belt was operated at a speed of 70 feet per second. Pitch data was taken for a maximum angle of attack range from -2 to +28 degrees at a sideslip angle of 0 degrees. Flap settings used were 0, 25, and 50 degrees. The horizontal stabilizer was moved as one piece with angle settings of 0, -4, -8 and -12 degrees. In the lateral case, data was taken for a sideslip angle range of -20 to +10 degrees with the model angle of attack at +6 and +14 degrees. All control surface deflections are positive with trailing edge down.

With the model in ground effect, auxiliary air for the ACLG system was supplied to the trunk systems at a flow rate of 1.451 ($\pm$ 0.05) pounds per second. This flow rate was fixed regardless of whether the model was in or out of ground effect with the ACLG system installed on the A-4. The flow rate was predetermined by the requirement that the air cushion pressure of the model in ground effect with zero tunnel speed must develop a lift force equal to the model's lift which is developed at the operating tunnel dynamic pressure. This is related to the full scale condition wherein cushion air pressure is determined by the aircraft static weight. With the model out of ground effect, the air flow rate stabilized at 1.440 pounds per second. Using a nominal model scale height of 0.050 inches to simulate air bag to ground clearance, measured average cushion pressure in the left air bag was 0.286 pounds per square inch (gage) and 0.290 pounds per square inch (gage) for the right air bag.

For all configurations, the out of ground effect condition corresponds to a model height above ground to wing span ratio of 1.14. Depending upon the configuration, the in ground effect conditions corresponds to a model height to span ratio of from 0.22 to 0.27. In all cases, the model height is the height of the A-4 model's center of gravity above the ground belt.

RESULTS AND DISCUSSION

Data from the wind tunnel program was cross-plotted and presented in Figures 9 through 19 for various stability parameters of interest. A limited amount of force data representative of the wind tunnel program is contained in the Appendix as additional information. This wind tunnel data shows that no abrupt changes are introduced into the lift and pitching moment characteristics of the A-4 in a SETOLS configuration. The lift and pitching moment curves are relatively smooth and quite linear up to 18 degrees angle of attack and trail off smoothly to 28 degrees. While there is a slight loss in control surface power, both stabilizer and flaps are effective over the range of angles of attack for take-off and landing with sufficient stabilizer control for trimming the aircraft. In both the carriage and deployment of the ACLG system, the A-4 SETOLS show a reduction in total drag over the conventional A-4 aircraft. Lateral and directional force and moments are likewise quite smooth with no introduction of abrupt changes in the characteristics with an ACLG installation.

Figure 9 shows that an A-4 in a SETOLS configuration results in a slight increase in the slope of the lift curve slope for the in-ground effect condition. This increase is present throughout the flap angle range from zero to full (50°) flaps. There is also a loss in the lift coefficient at zero angle of attack associated with a deployed ACLG system occurring at both zero and full flap settings (see Figure 10). However, at the intermediate flap angles, there is an increase in the zero angle of attack lift coefficient. Figure 11 shows that a nose up pitching moment at zero lift is produced on the A-4 configuration by the installation of the ACLG system. This additional destabilizing pitching moment is present regardless of flap or horizontal stabilizer setting. The drag at zero lift is appreciably lower for the A-4 SETOLS configuration. At 50° flap deflection, the addition of an ACLG produced a drag reduction on the order of 25 percent or more (see Figure 12). This change in the pitching moment and drag characteristics at zero lift is probably due in part to components of a thrust force generated by the auxiliary air exhausting from the air bags. An unstable shift in the neutral point of the A-4 aircraft also occurs with the conversion to a SETOLS configuration. Although still statically stable with a static margin of 12 to 14 percent, this shift is approximately $0.04\bar{c}$ for the landing configuration. Figure 13 presents a comparison of the static margin, slope of the pitching moment-lift curve, for the A-4 with and without an ACLG system for a $C_L = 1.0$.

The dihedral effect was improved for a SETOLS configured A-4 aircraft. This increase in lateral stability, rolling moment-sideslip curve slope, is shown in Figures 14 and 15. For 6 and 14 degrees angle of attack, the dihedral effect is improved by over 25 percent for the in-ground effect condition. However, from the limited data presented in Figure 15, a loss in dihedral effect occurs when the A-4 SETOLS aircraft is out-of-ground effect, i.e., during landing approach. It appears that the addition of vertical stabilizers on the horizontal tail will recover much of this loss. In the case of directional stability, the addition of an ACLG system produces a large loss in weathercock stability. Figures 16 and 17 show this loss extends over the range of stabilizer and flap angles for both 6 and 14 degrees angle of attack. The in-ground effect loss in directional stability for the A-4 SETOLS is on the order of 40 percent. The addition of auxiliary vertical stabilizers to the A-4 SETOLS in this instance resulted in a configuration more directionally stable than the A-4 with a conventional landing gear. Figures 18 and 19 show that the side force derivative $-C_{y_\beta}$ of the A-4 SETOLS is less than the conventional A-4 at 14 degrees angle of attack; but is higher at 6 degrees angle of attack than the conventional A-4 for both the 6 and 14 degree condition. Compared to the conventional A-4, the ACLG configuration shows little change in the side force derivative between the in-ground and out-of-ground effect condition.

The effect of an ACLG system on the aerodynamic characteristics of an A-4 aircraft is small when compared to the large change in its physical characteristics. The largest effect is the reduction in static margin and in the directional (weather-cock) stability. However, the A-4 SETOLS still retains adequate longitudinal stability and the use of additional vertical stabilizers on the horizontal tail area more than compensates for any loss in directional stability. Without adequate directional control, an ACLG equipped aircraft would be extremely sensitive to cross winds during ground roll in the take off and landing phase. The absence of direct physical contact with the ground, i.e., no wheels would seem to require a SETOLS configuration to have more directional stability than a conventional A-4. Less thrust for landing and take off along with smaller tail deflections for trim are side benefits for the ACLG system.

CONCLUSIONS

Analysis of the wind tunnel data show the following effects from installation of an air cushion landing gear on the A-4 aircraft in place of the conventional wheel gear for the in-ground effect (landing) condition:

(1) An increase in the lift curve slope and a decrease in the lift at zero angle of attack

(2) A reduction of 25 percent or more in drag at zero lift and a 50 percent reduction in total drag.

(3) A nose up pitching moment producing an unstable shift of approximately $0.04\bar{c}$ in the neutral point and a 10 to 25 percent reduction in the static margin.

(4) Lateral stability was improved by over 25 percent at 6 and 14 degrees angle of attack.

(5) Directional stability was decreased by over 50 percent at 6 and 14 degrees angle of attack.

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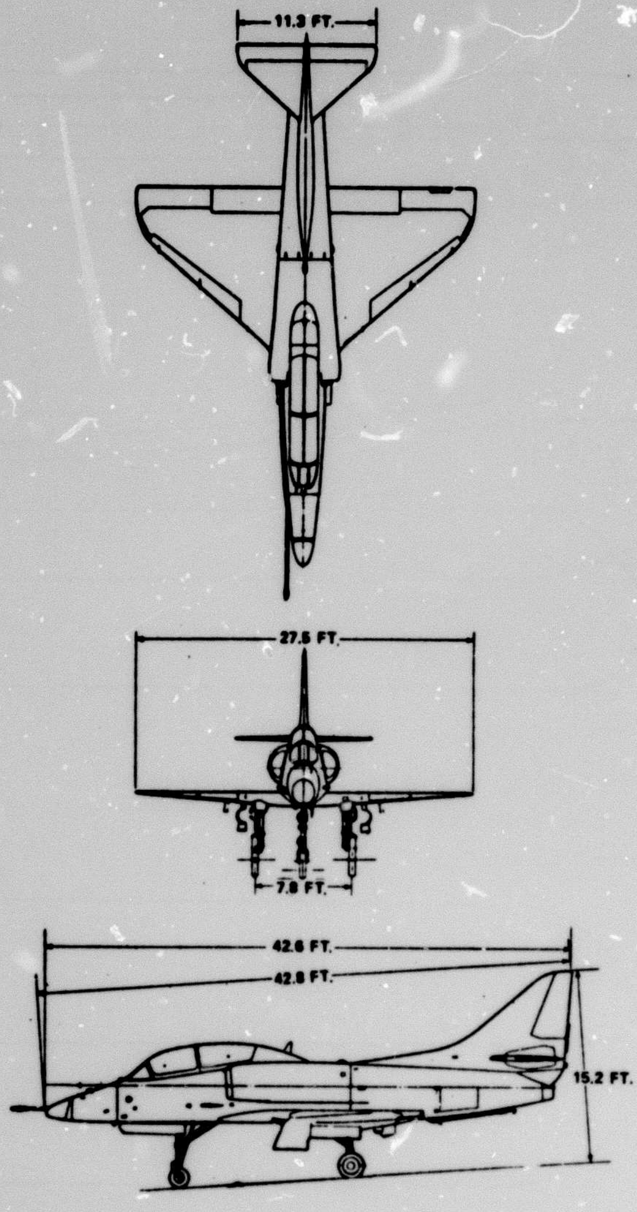


Figure 1 - General Dimensions of Full Scale TA-4F Aircraft

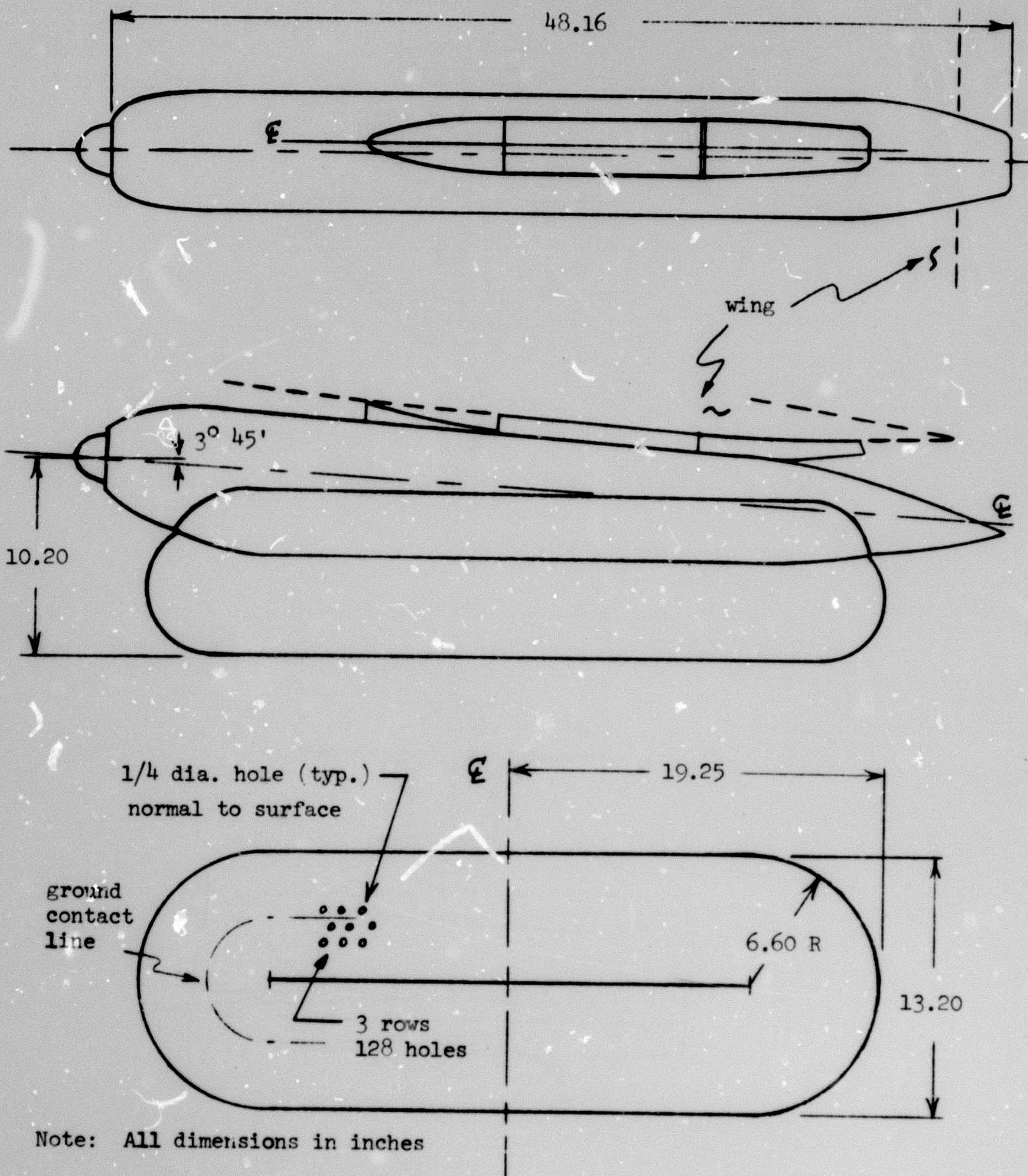


Figure 2 - General Dimensions of 22% Scale Air Cushion Landing Gear System

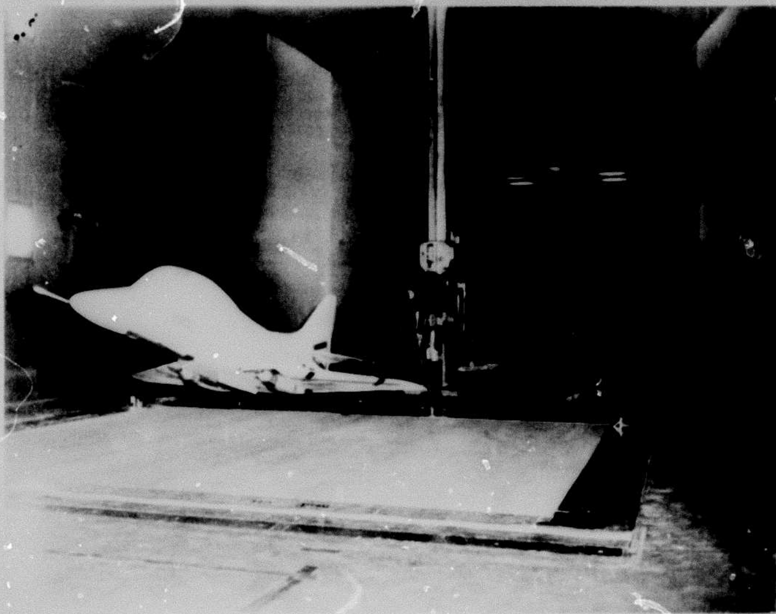


Figure 3 - Aircraft in Clean Configuration

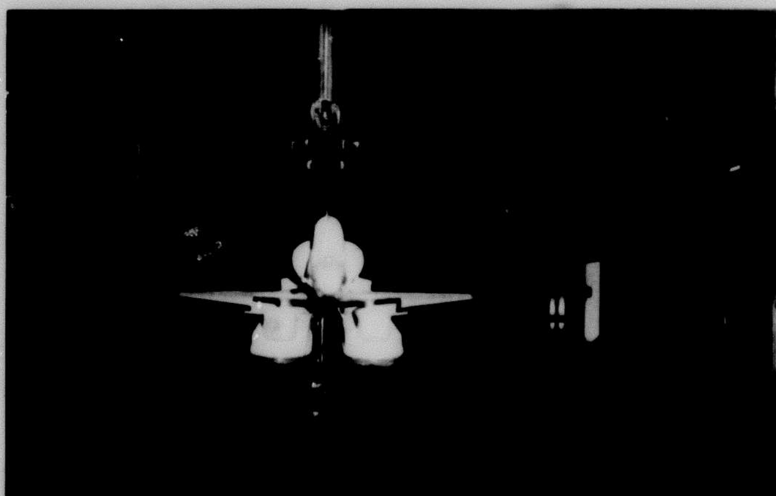


Figure 4 - Aircraft with Air Cushion Landing Gear Deployed

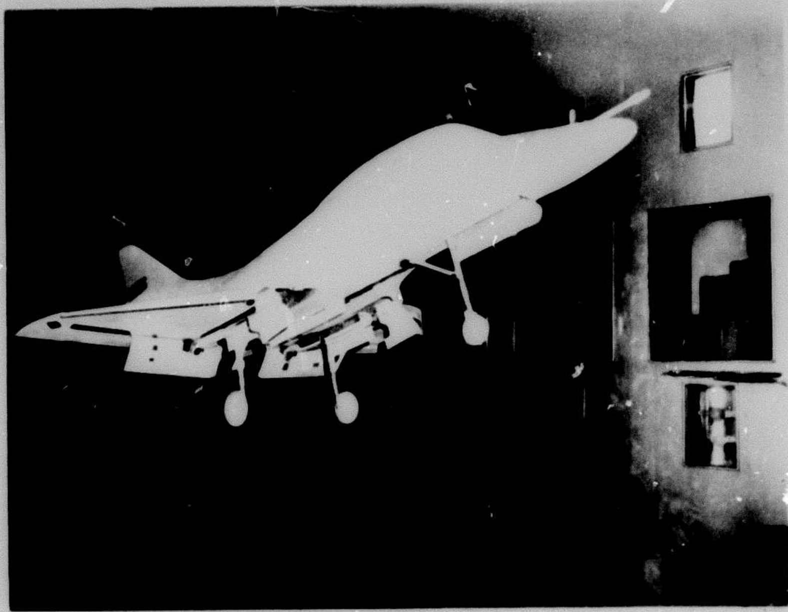


Figure 5 - Aircraft with Conventional Landing Gear Deployed

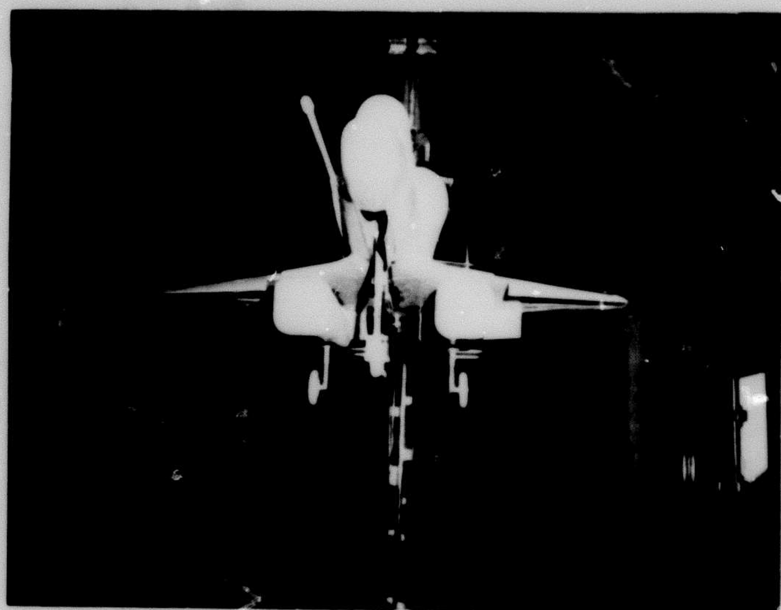


Figure 6 - Aircraft with Air Cushion Landing Gear Retracted

Figure 7 - Close Up Details of Air Bags in Deployed Configuration

Figure 8 - Aft Section of Model Showing Additional Vertical Stabilizers Installed

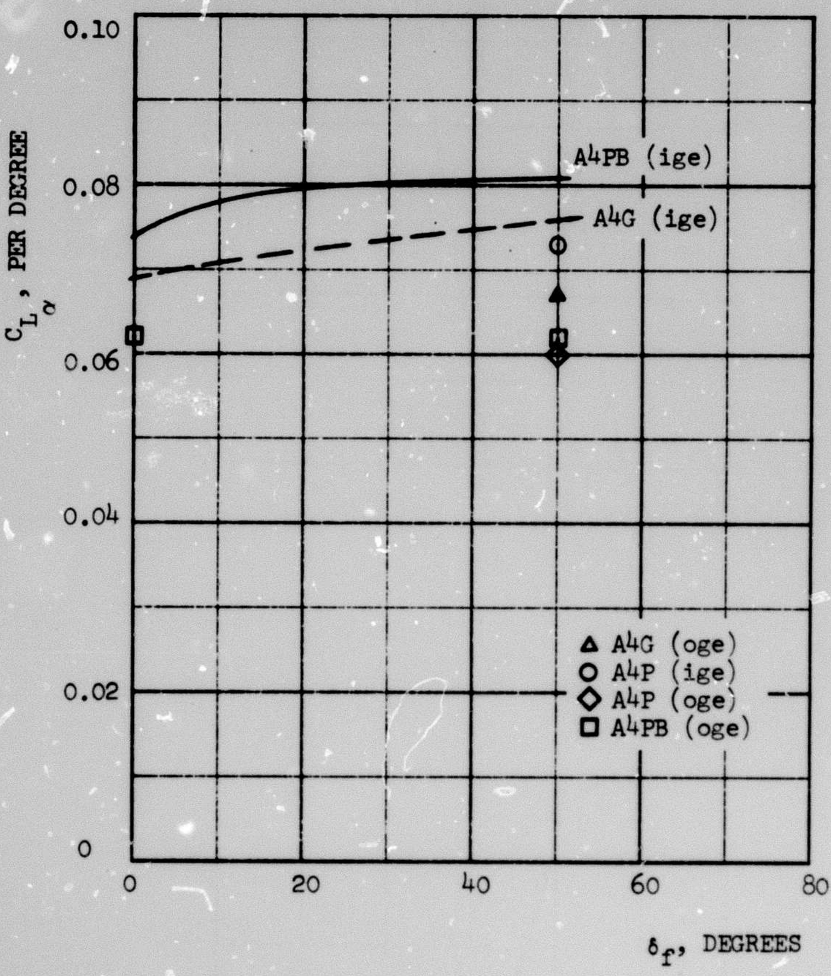


Figure 9 - Variation of Lift Curve Slope for
$\delta_h = -8^o$ at Zero Angle of Attack

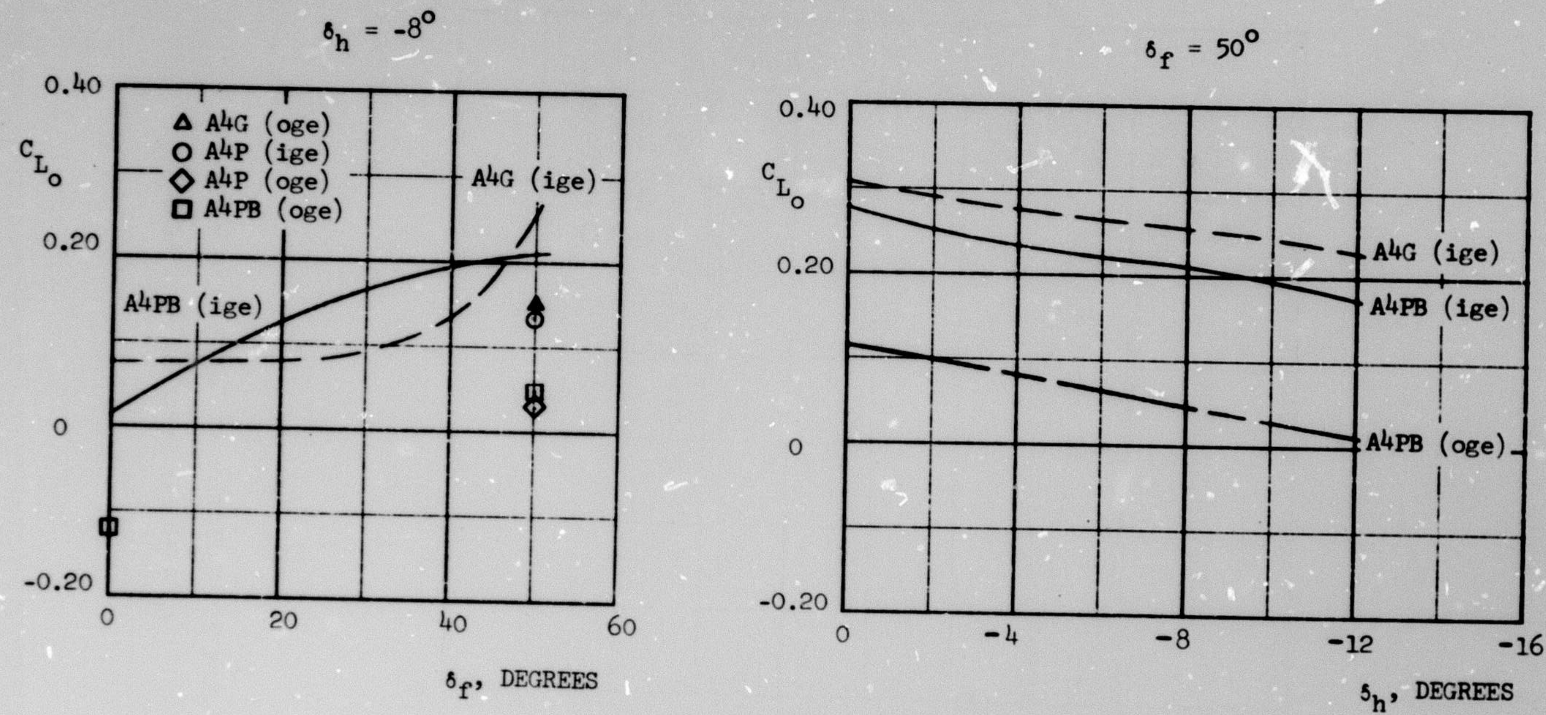


Figure 10 - Variation of Lift Coefficient at Zero Angle of Attack

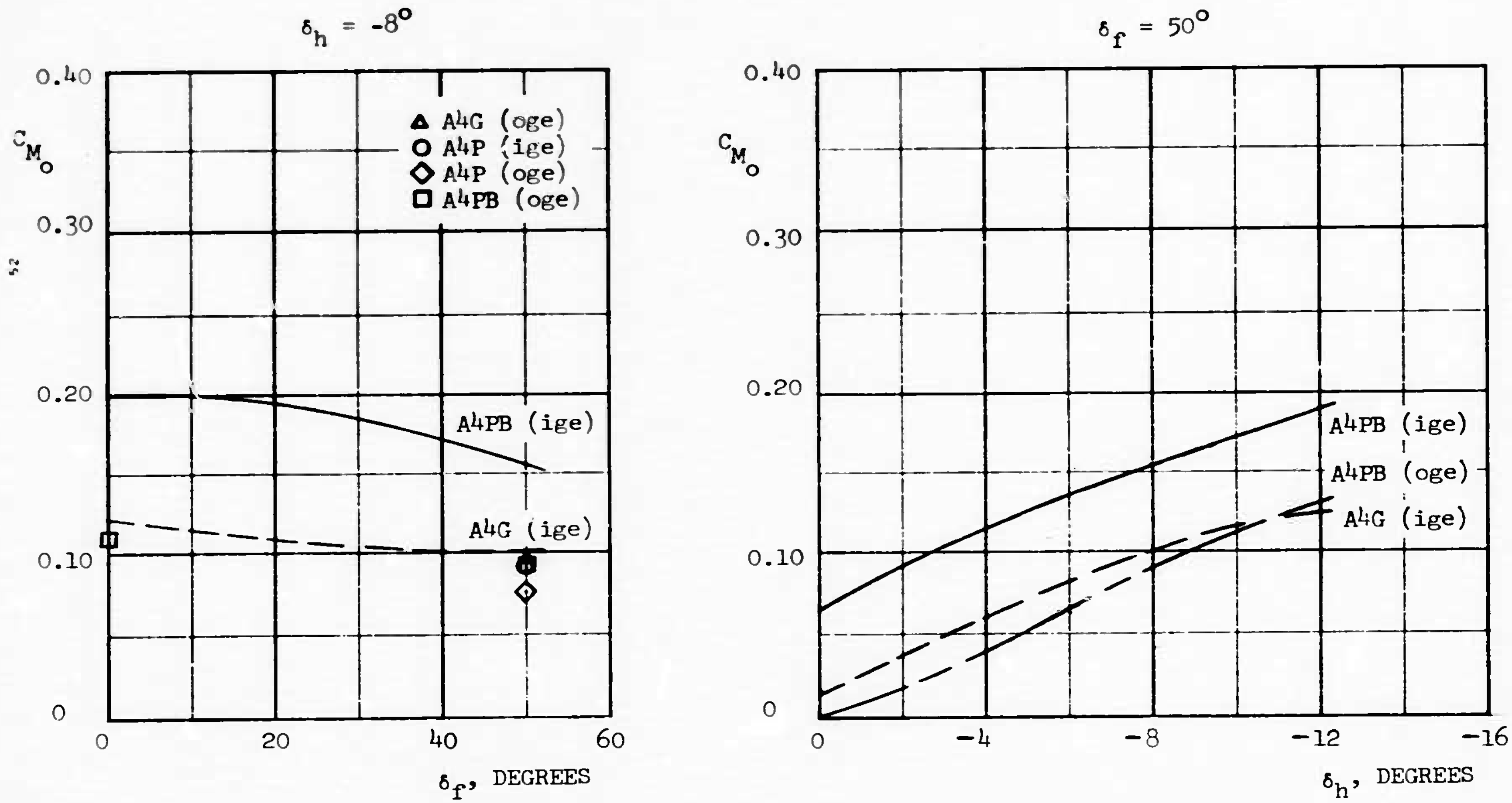


Figure 11 - Variation of Pitching Moment Coefficient at Zero Lift

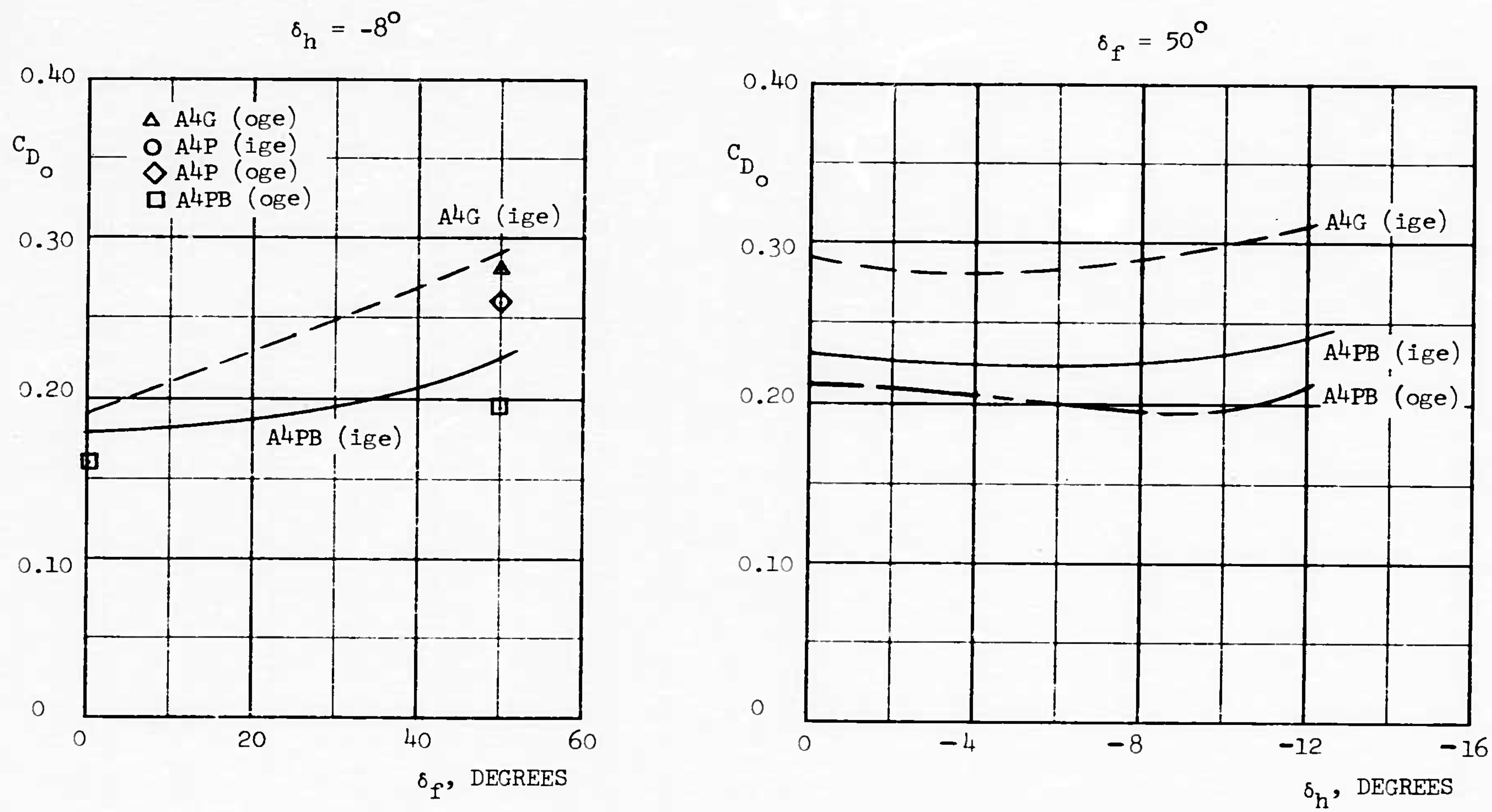


Figure 12 - Variation of Drag Coefficient at Zero Lift

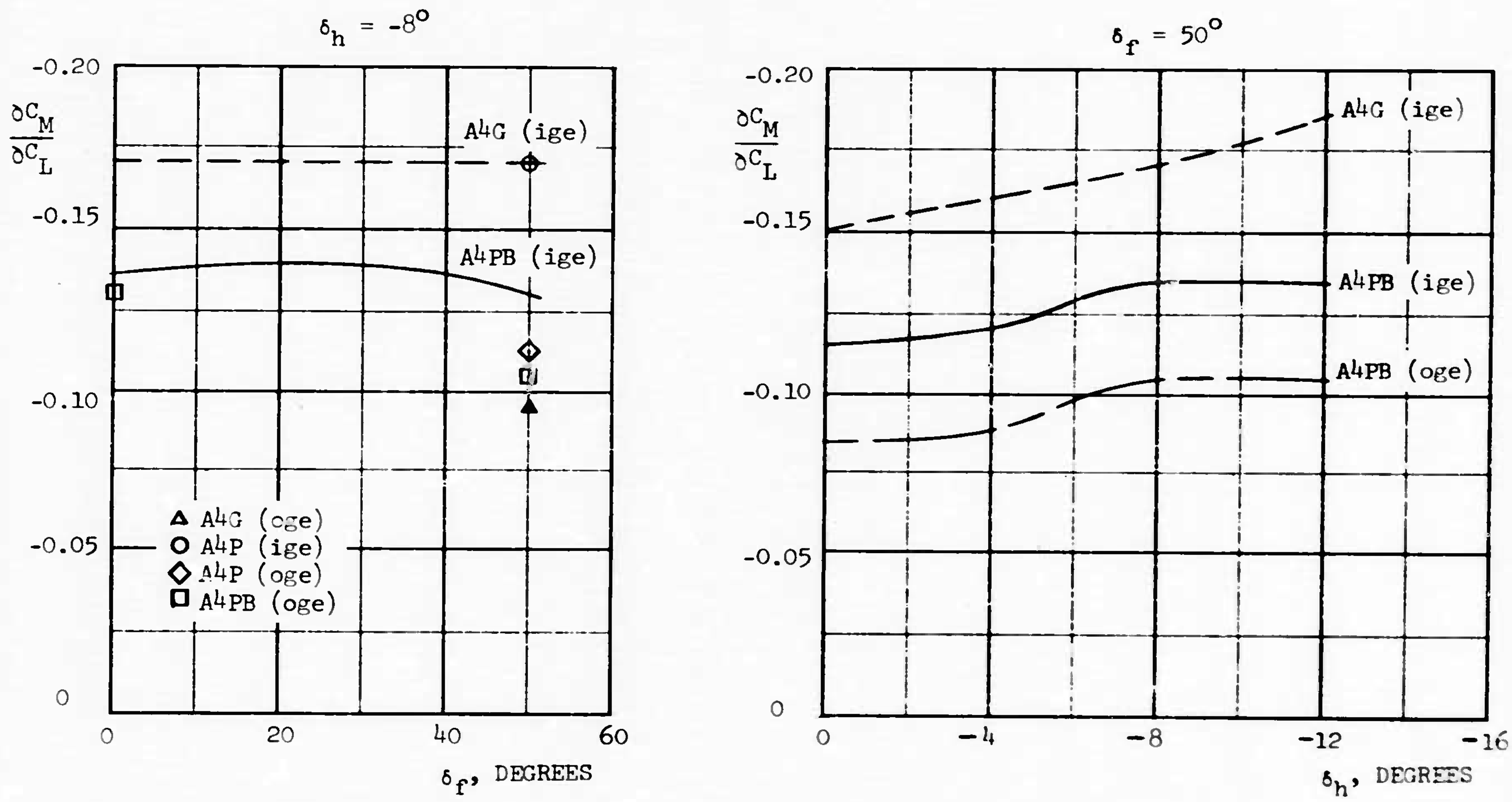


Figure 13 - Variation of Pitching Moment - Lift Curve Slope

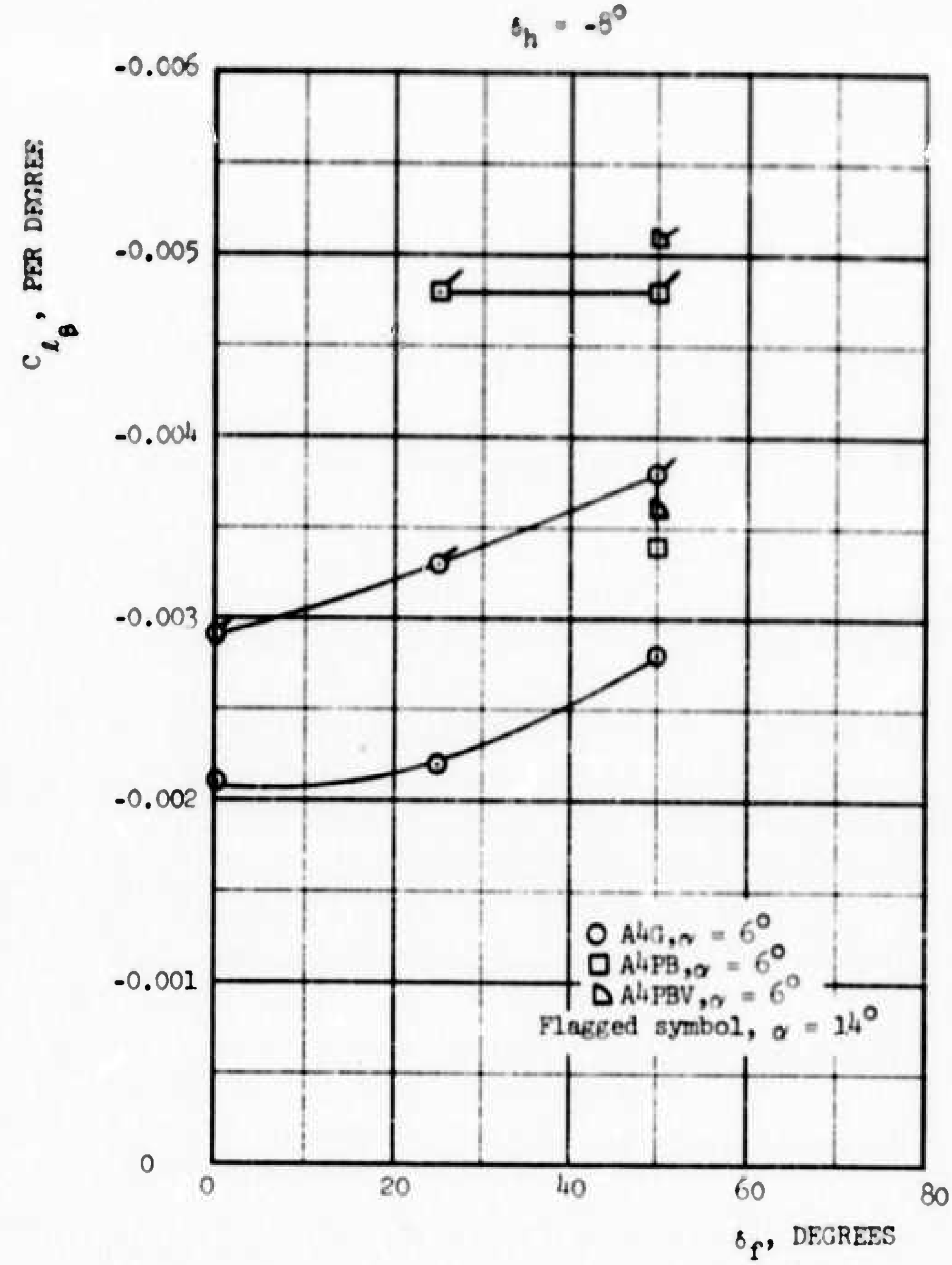


Figure 14 - Variation of Rolling Moment - Sideslip Curve Slope with Flap Deflection for In-Ground Effect

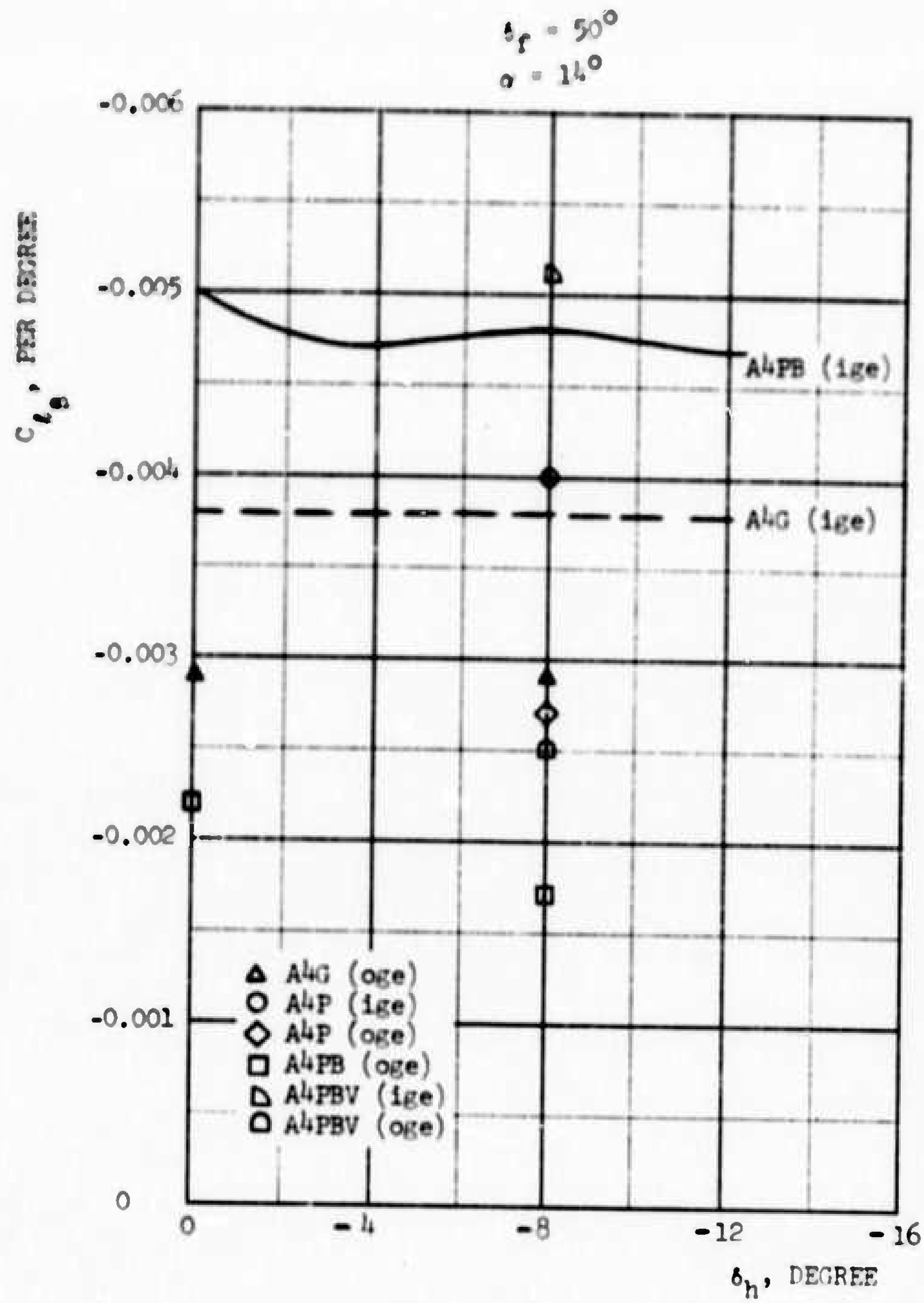


Figure 15 - Variation of Rolling Moment - Sideslip Curve Slope with Stabilizer Deflection

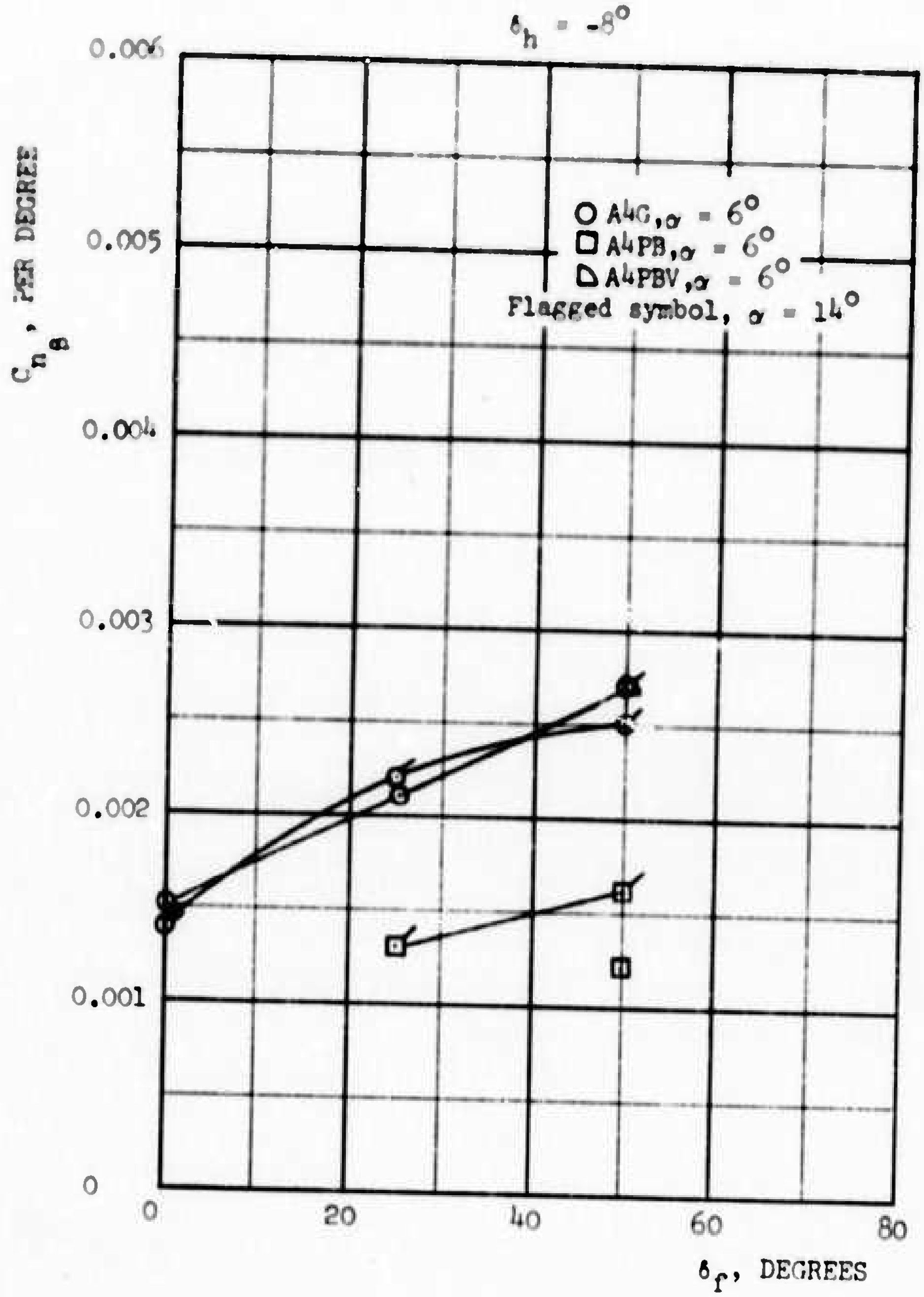


Figure 16 - Variation of Yawing Moment - Sideslip Curve Slope with Flap Deflection for In-Ground Effect

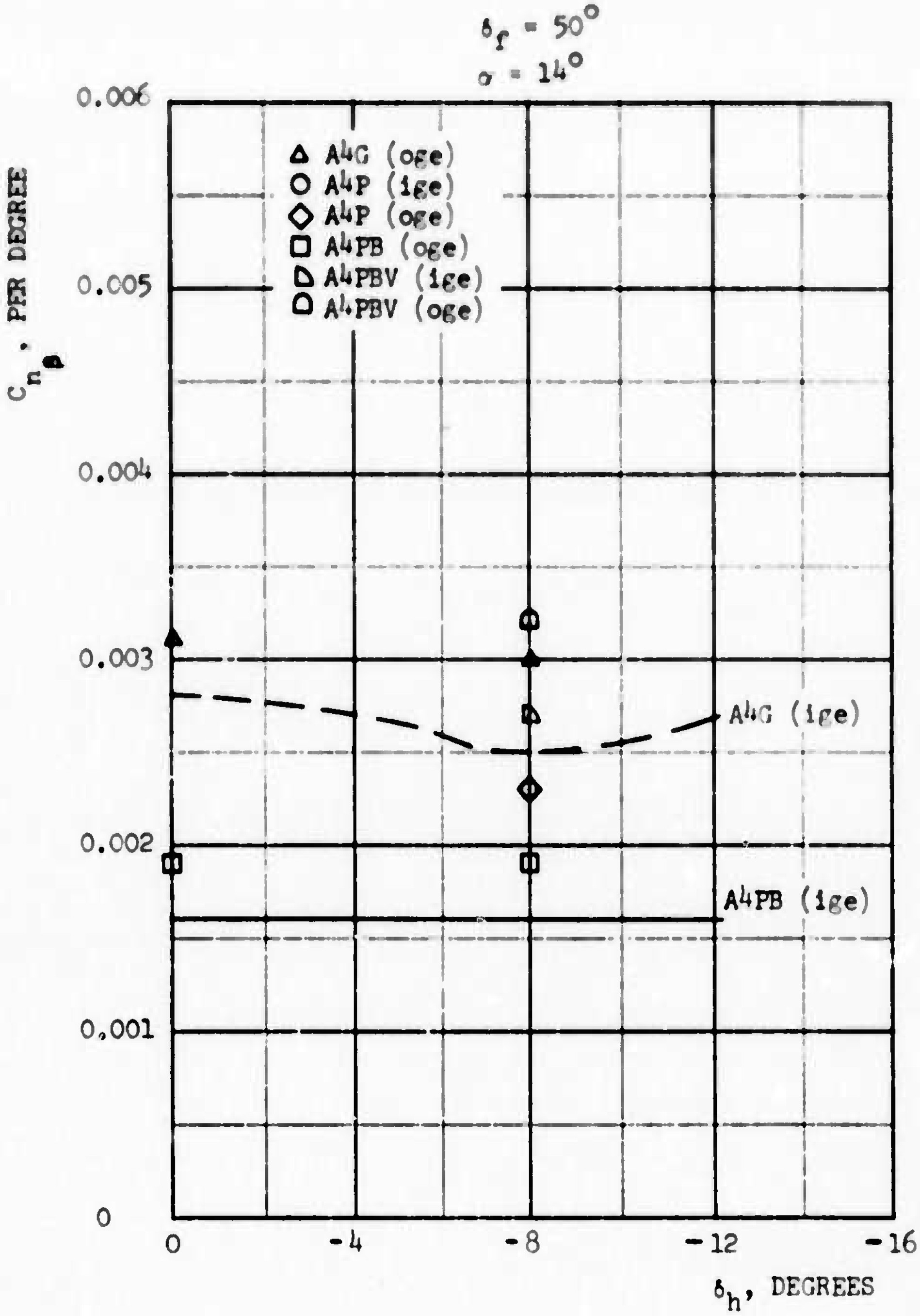


Figure 17 - Variation of Yawing Moment - Sideslip Curve Slope with Stabilizer Deflection

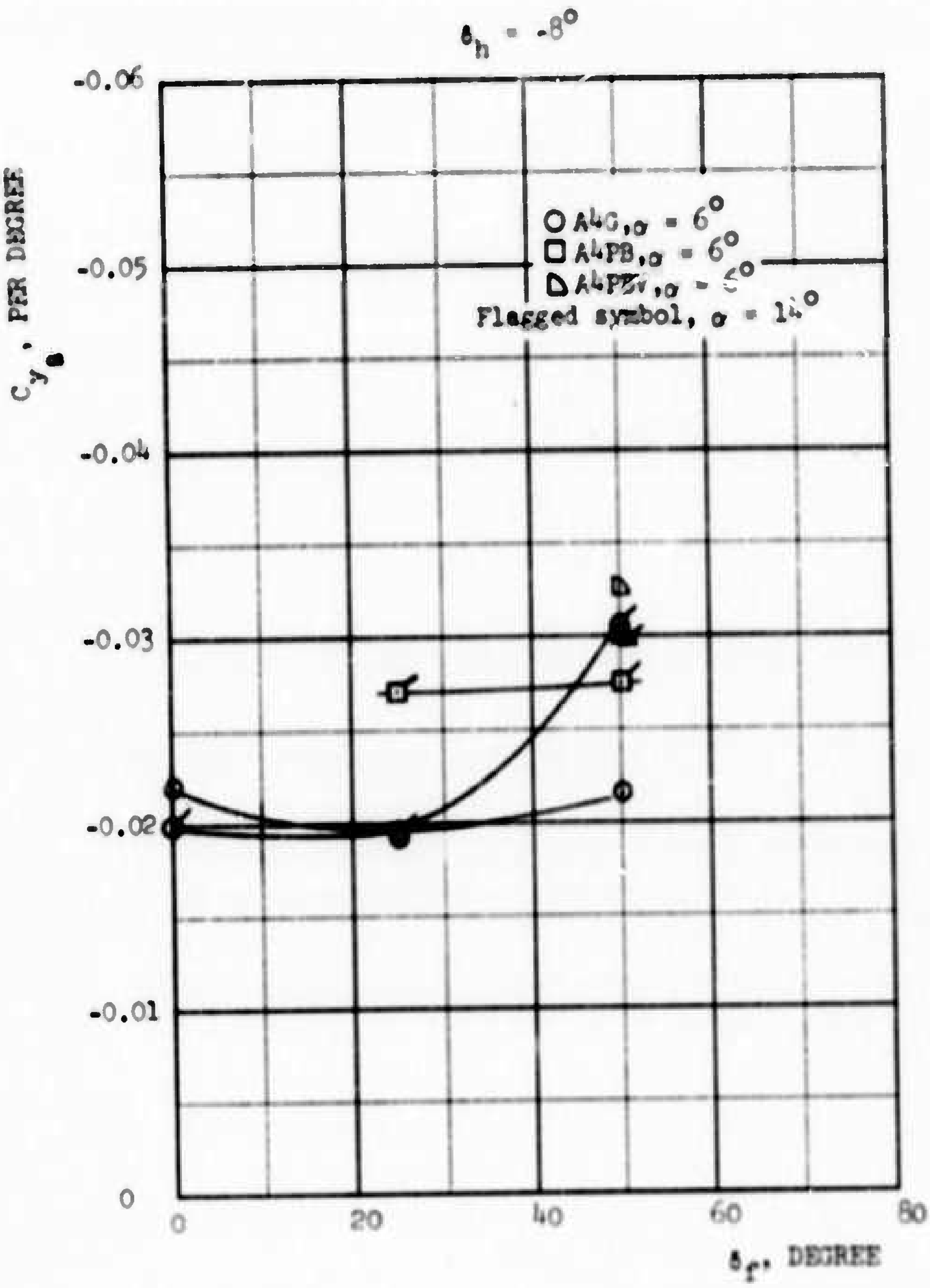


Figure 18 - Variation of Side Force - Sideslip Curve Slope with Flap Deflection for In-Ground Effect

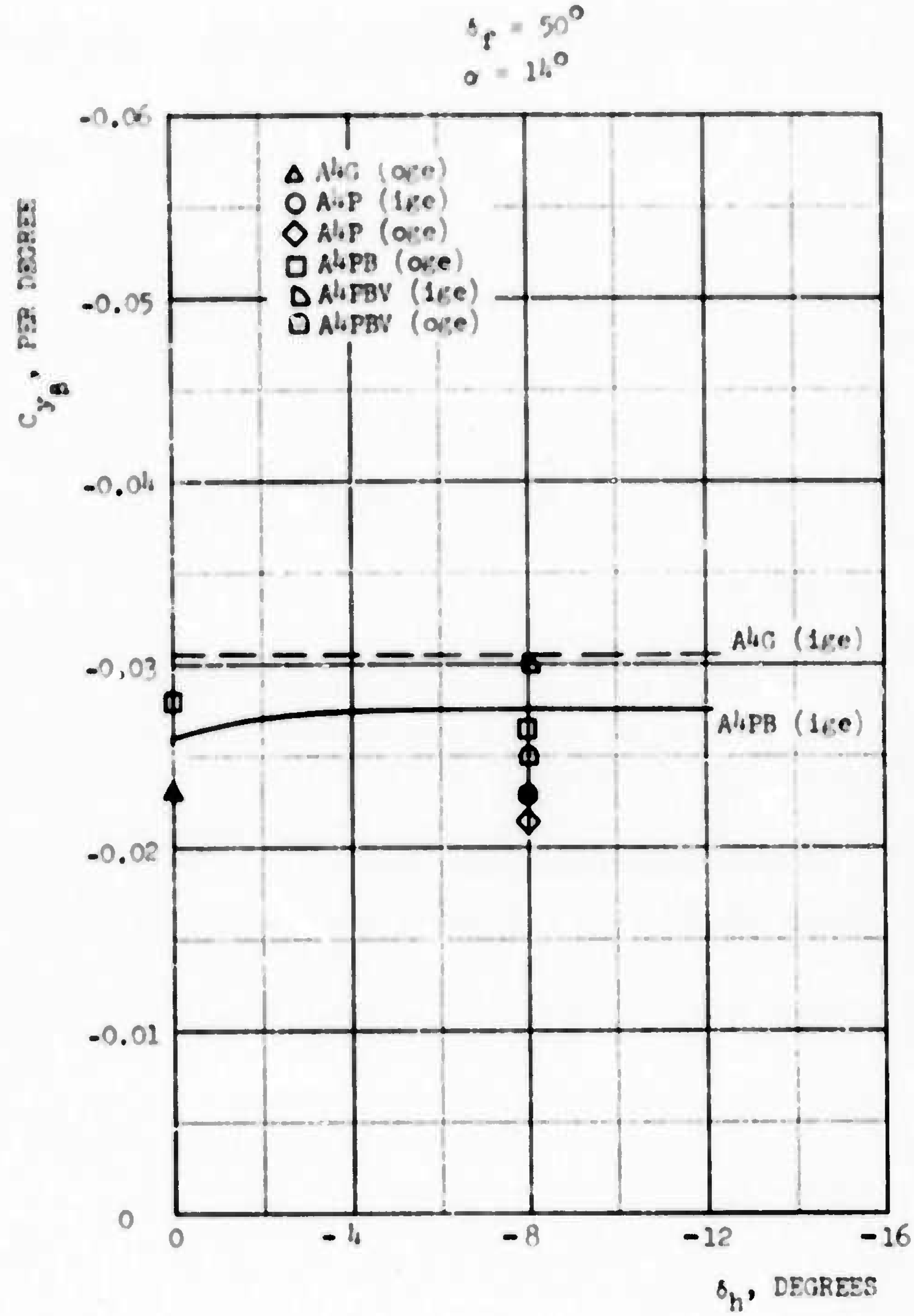
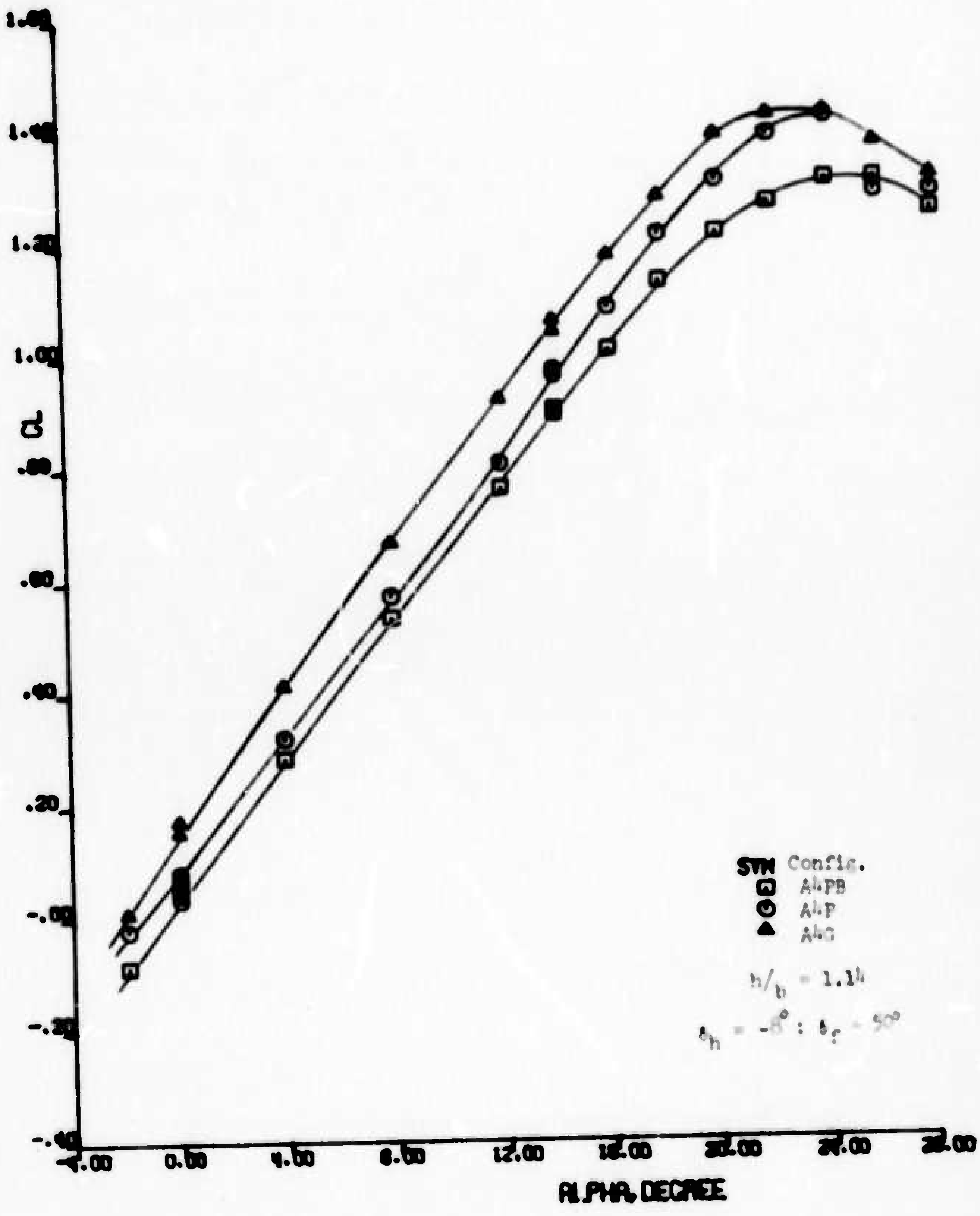


Figure 19 - Variation of Side Force - Sideslip Curve Slope with Stabilizer Deflection

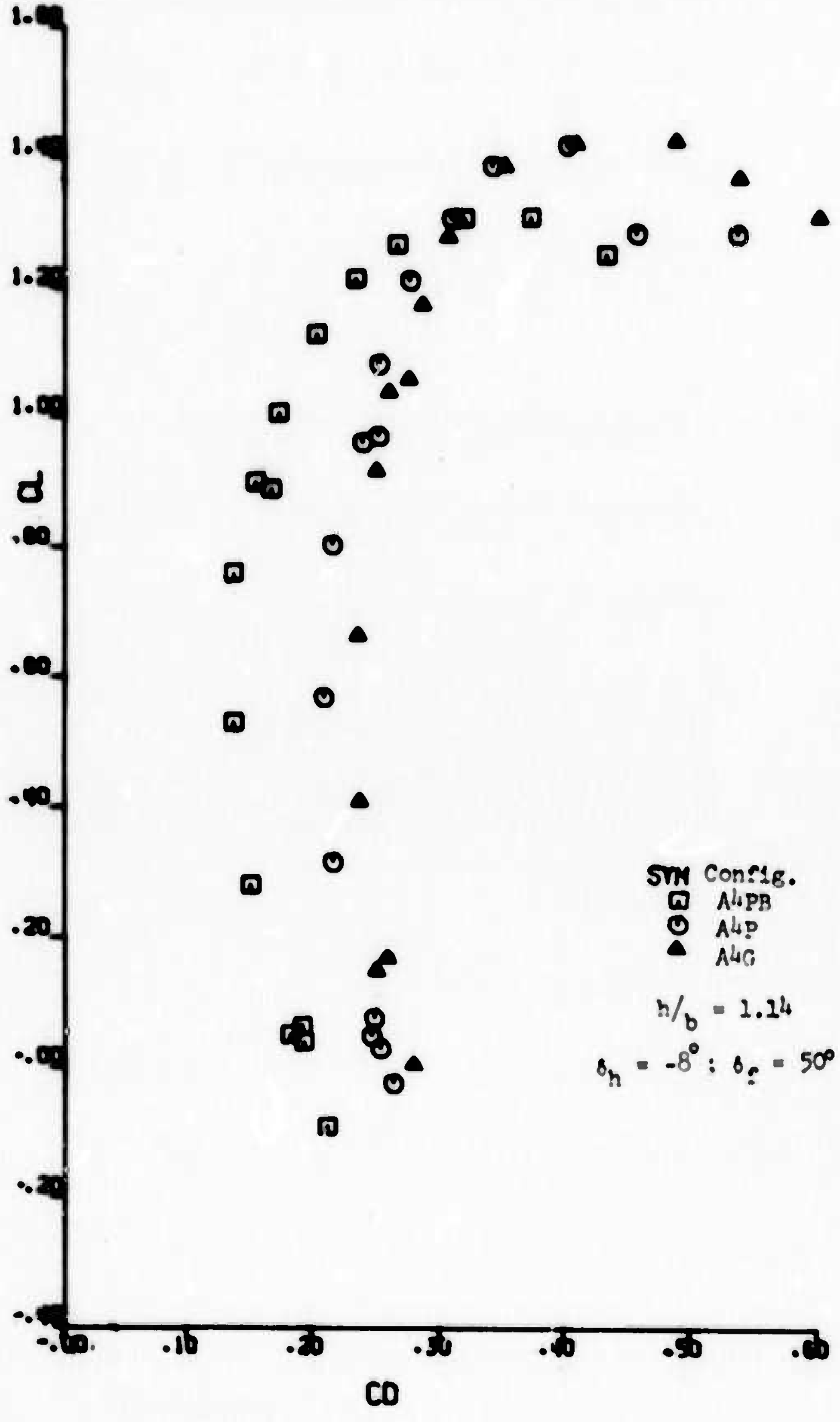
APPENDIX

A representative sampling of the wind tunnel data in the form of force and moment coefficients is presented on pages 28 through 45. These and other computer plotted data were used to determine the stability parameters discussed in the main text of this report and presented in Figures 9 through 19. The coefficients are defined in the main text and the computer notation for these plots are:

ALPHA	Angle of attack
BETA	Angle of sideslip
CD	Drag coefficient
CL	Lift coefficient
CM	Pitching moment coefficient
CRM	Rolling moment coefficient
CY	Side force coefficient
CYM	Yawing moment coefficient



CL
ALPHA, DEGREE
SYM Config.
A4PB
A4P
A4G



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CD
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A4G
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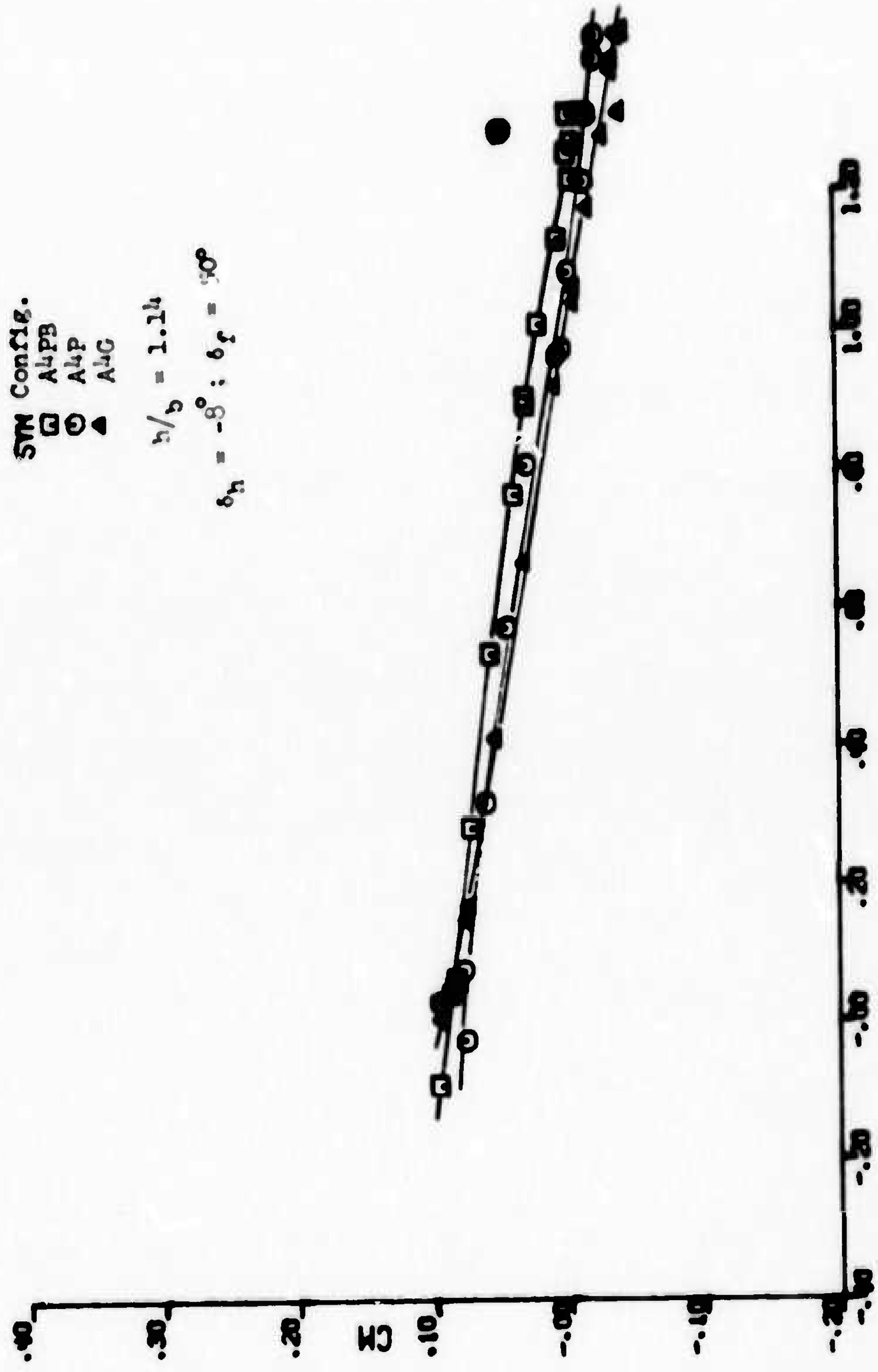
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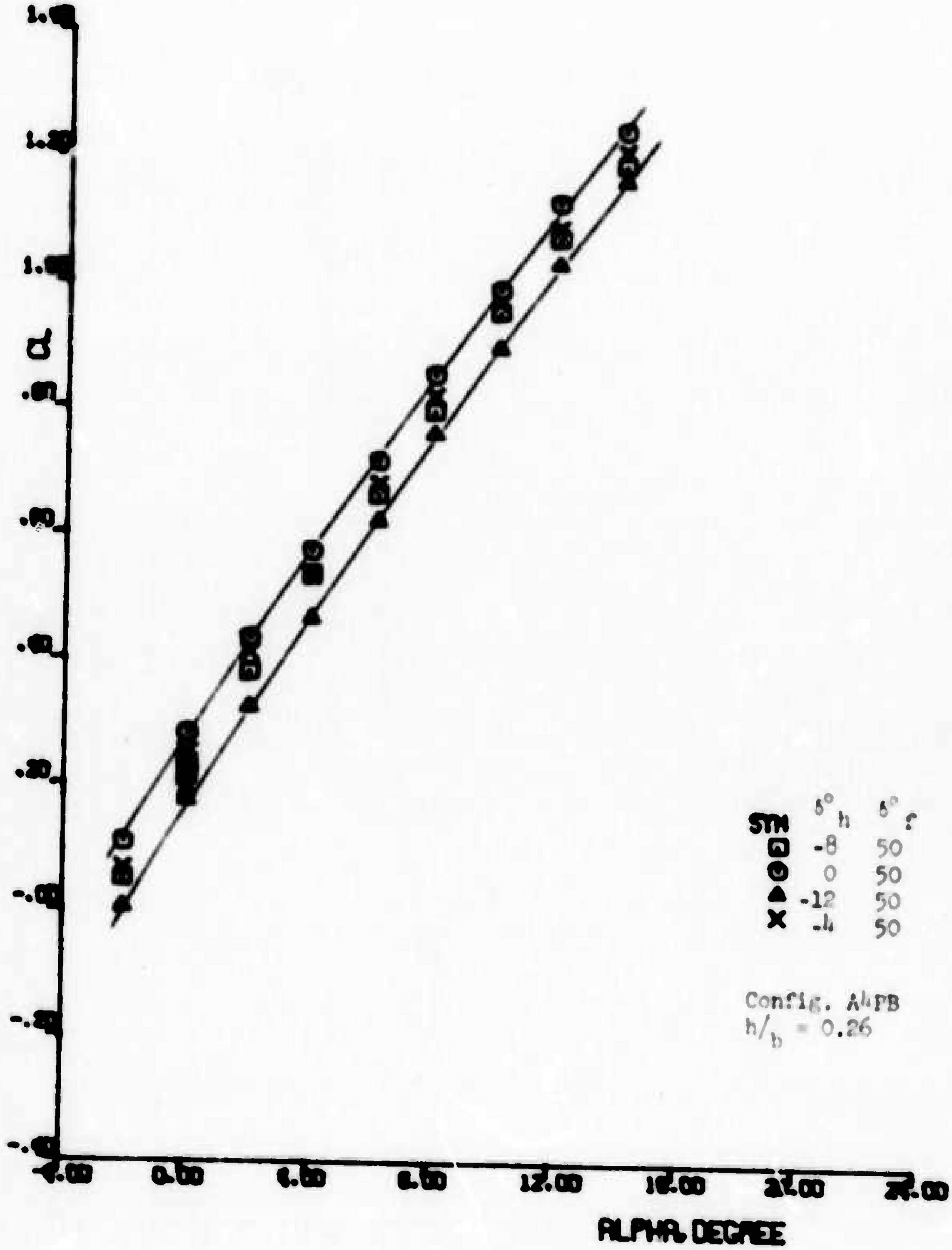
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12.00
-8 50
0 50
-12 50
-4 50
Config. A4PB
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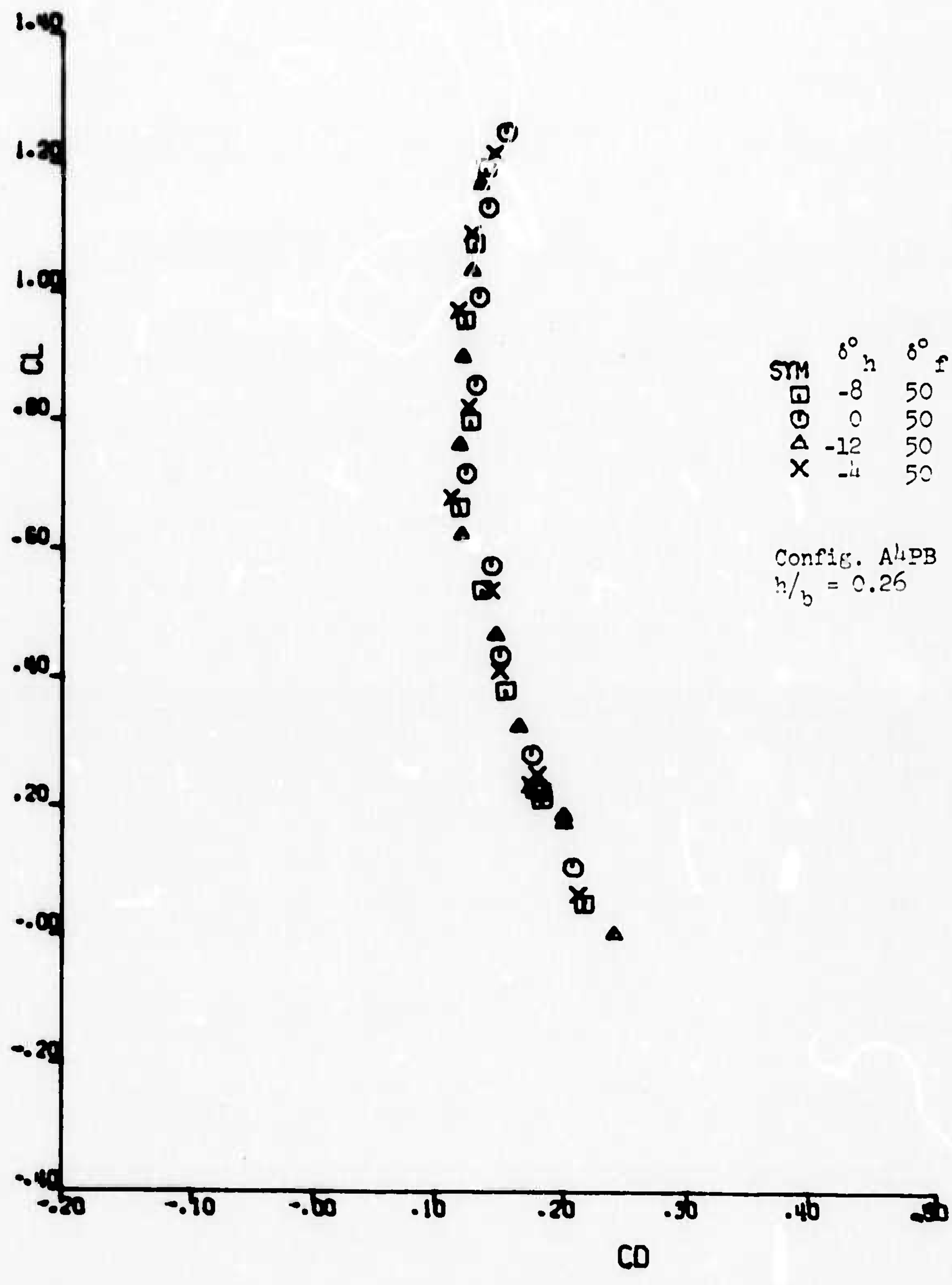
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1.20
1.00
CL
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.60
.40
.20
-.00
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-.40
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-.00
.10
.20
.30
.40
.50
CD
SYM δ°h δ°f
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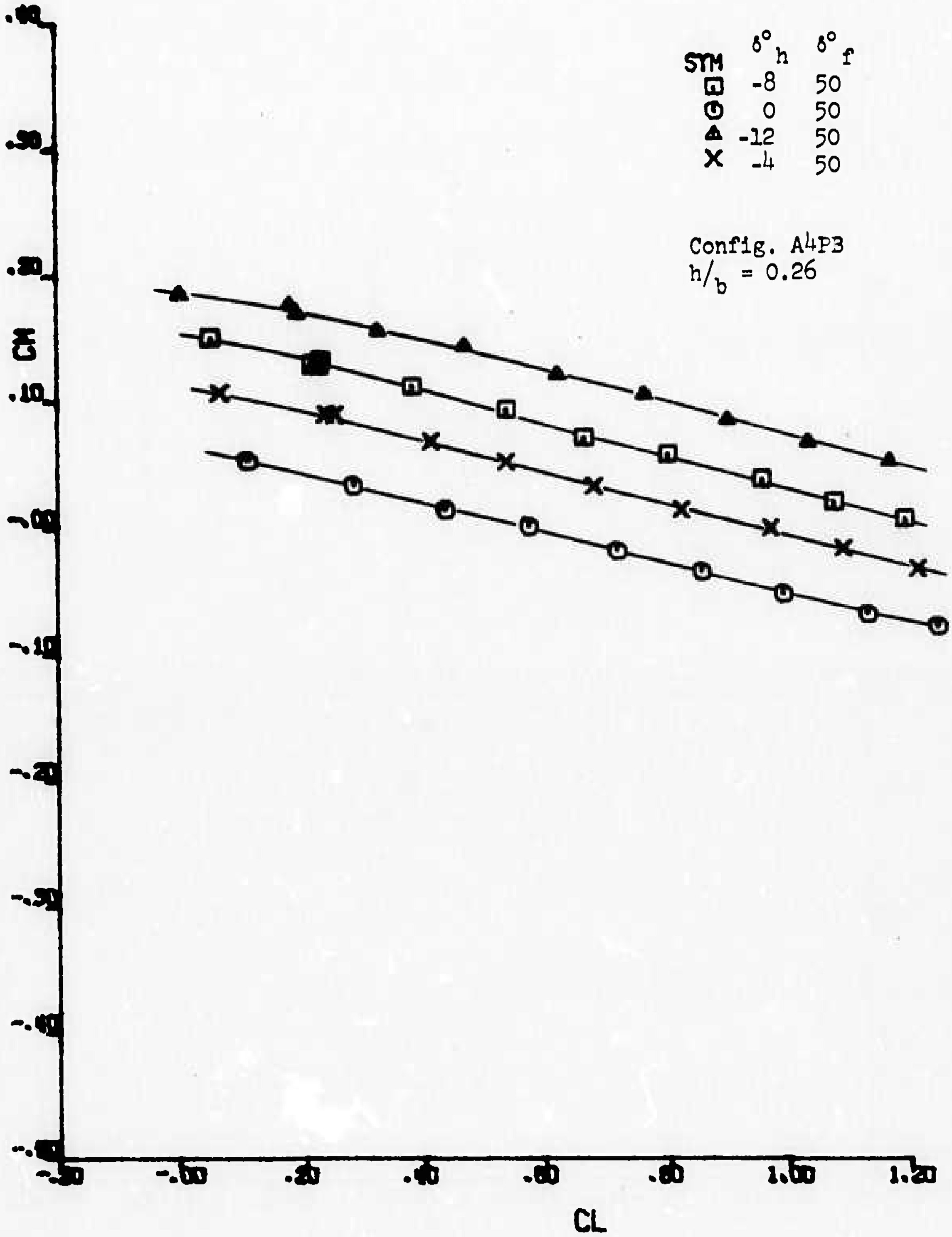
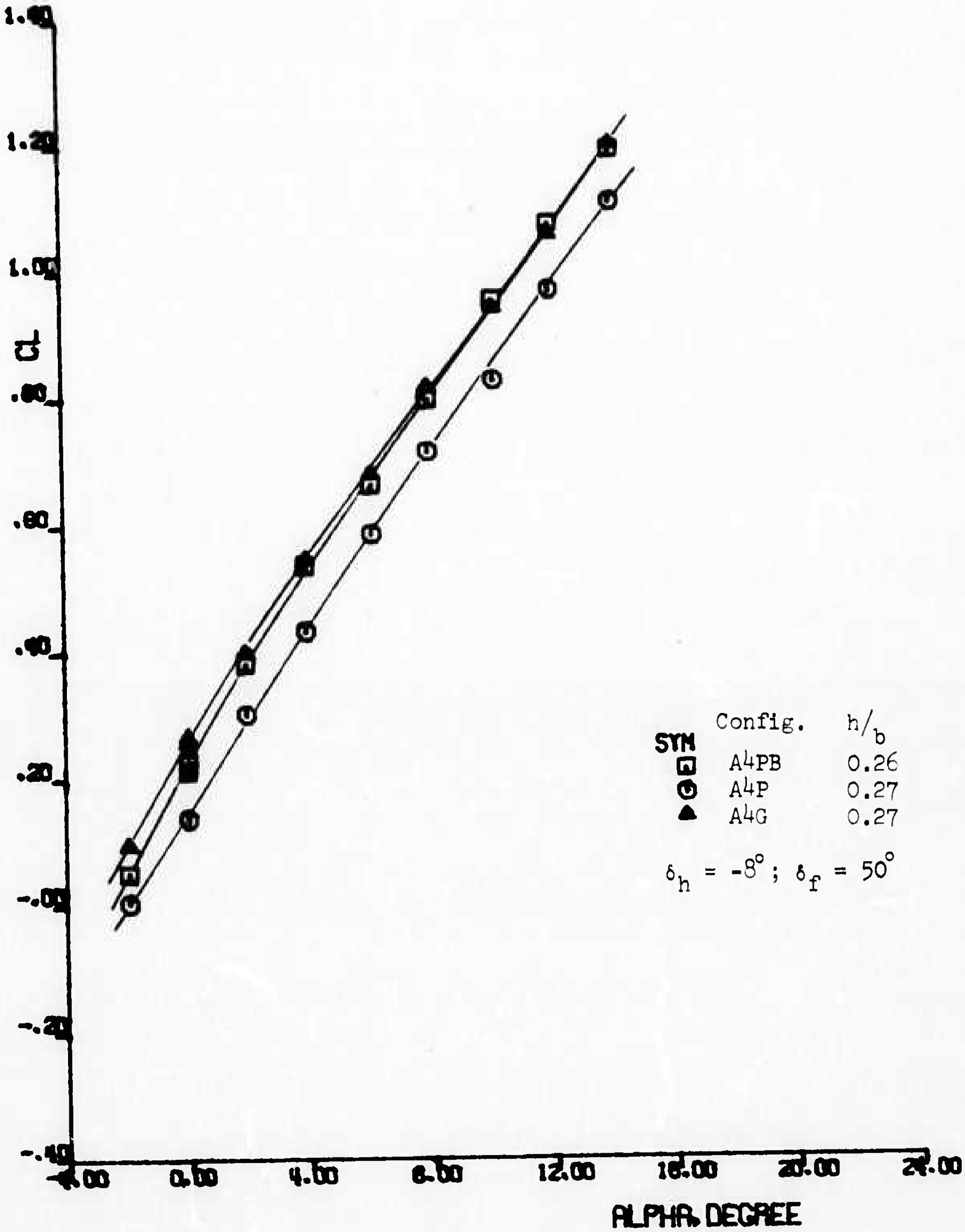
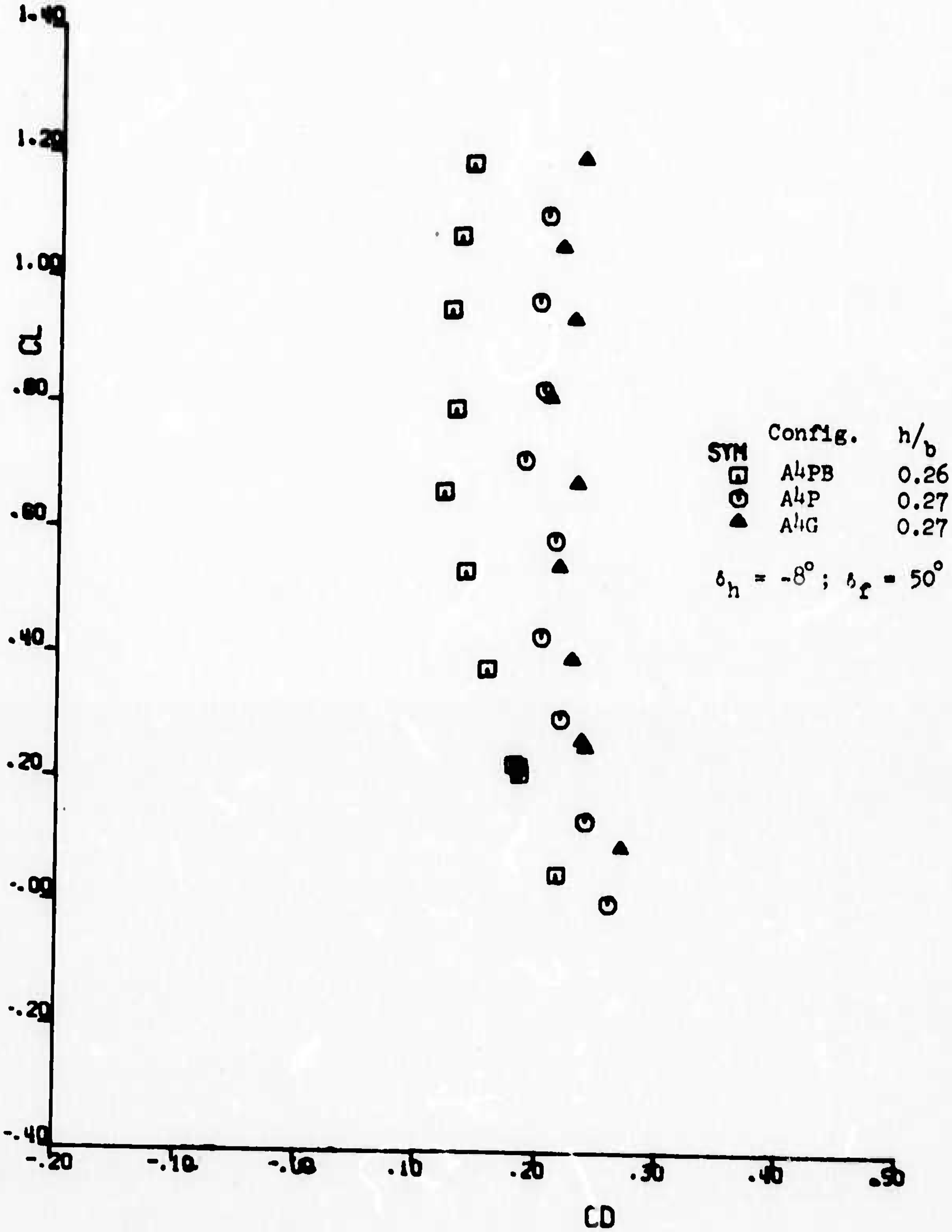
0 50
-12 50
-4 50
Config. A4PB
h/b = 0.26

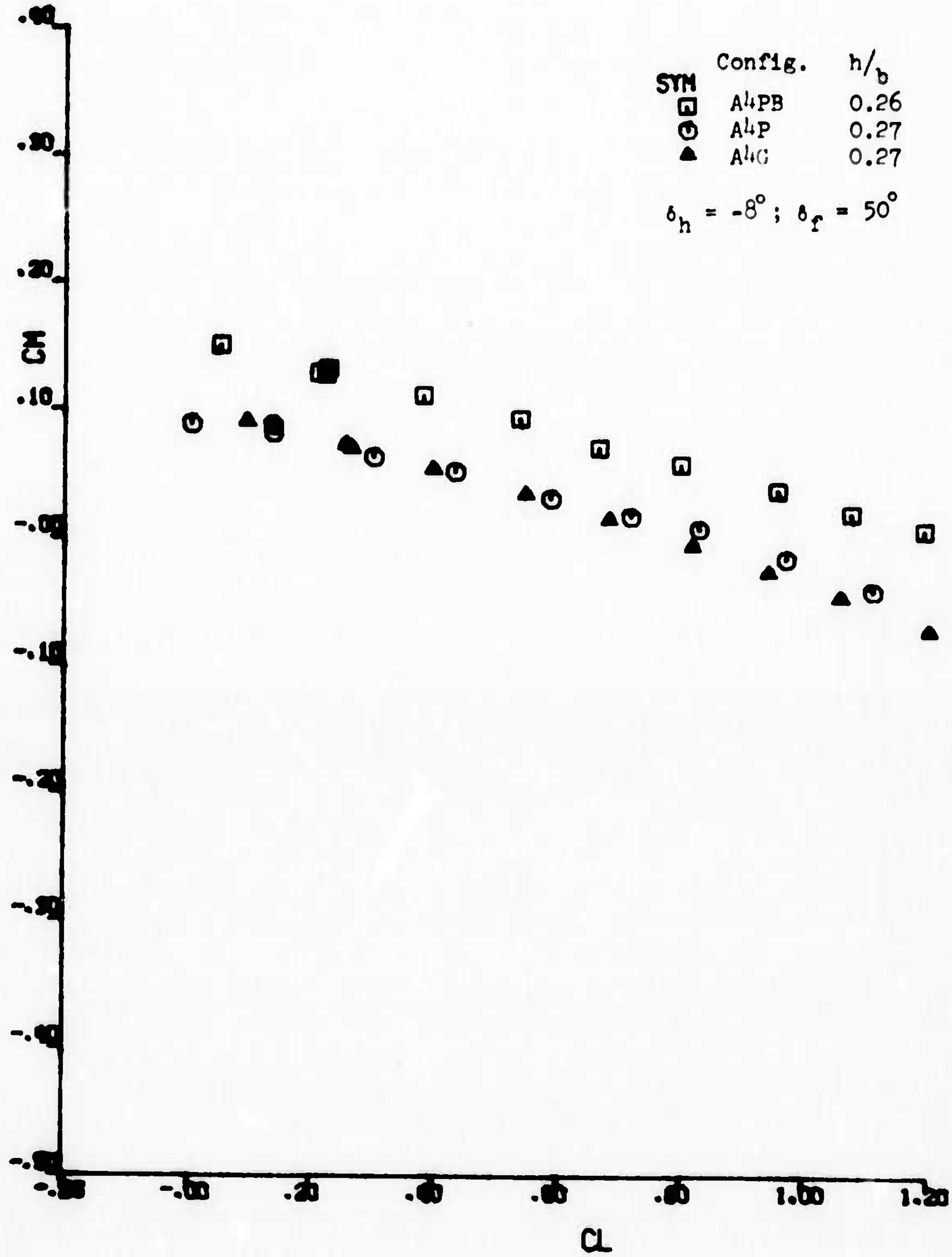

STM δ°h δ°f
-8 50
0 50
-12 50
-4 50
Config. A4P3
h/b = 0.26
CM
CL



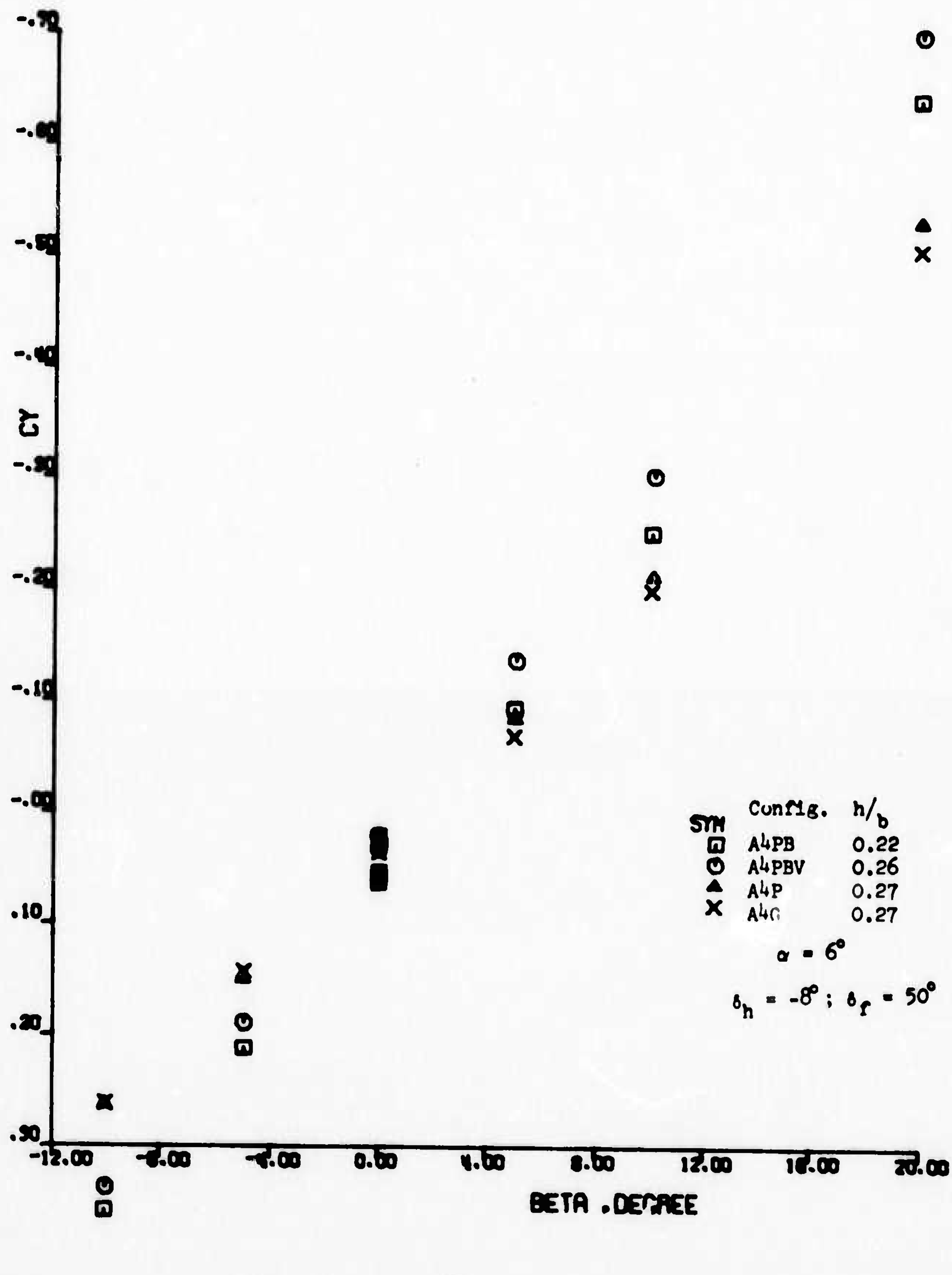
1.40
1.20
1.00
CL
.80
.60
.40
.20
-.00
-.20
-.40
-4.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
ALPHA, DEGREE
SYM Config. h/b
A4PB 0.26
A4P 0.27
A4G 0.27
$\delta_h = -8°; \delta_f = 50°$



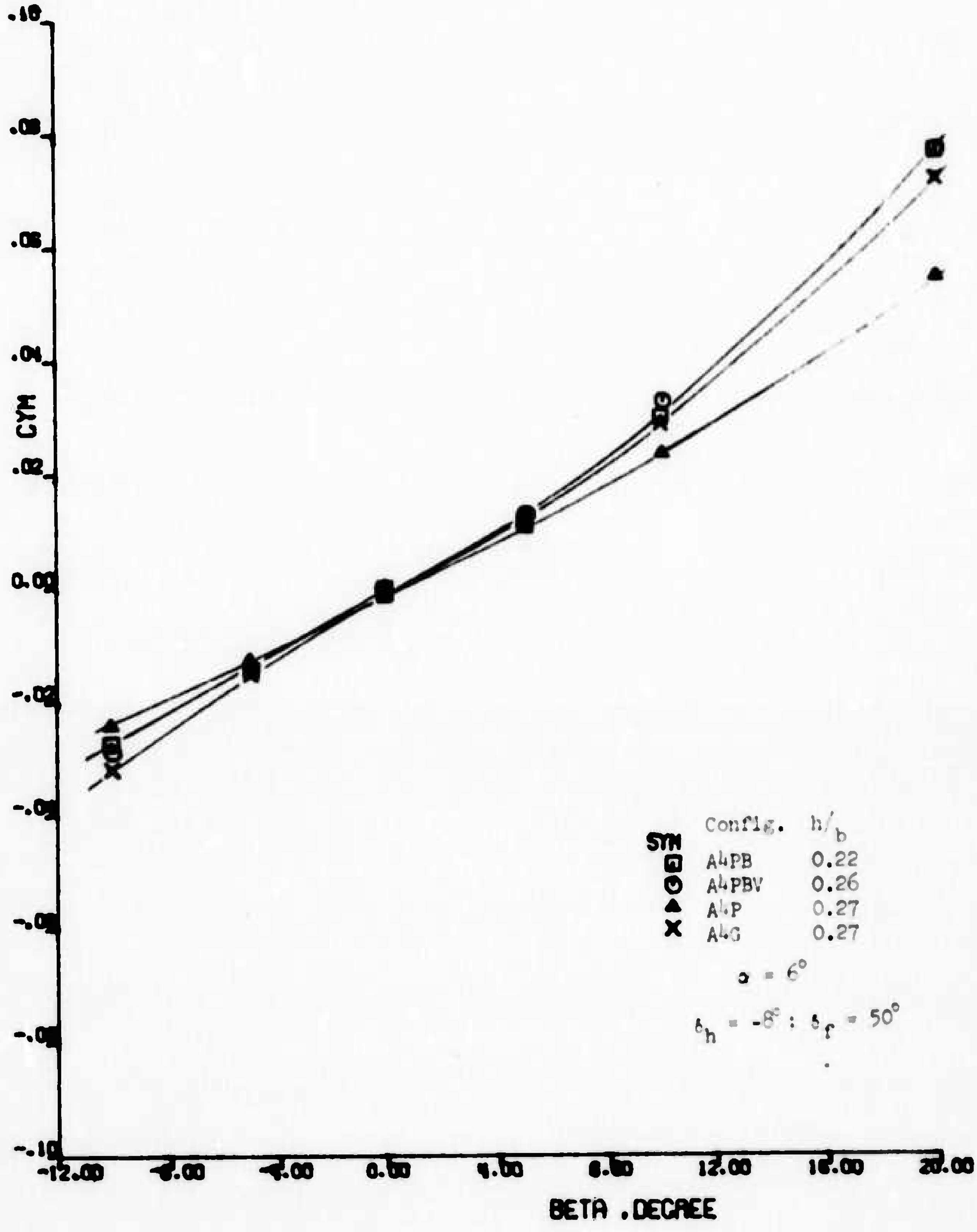
1.40
1.20
1.00
CL
.80
.60
.40
.20
-.00
-.20
-.40
-.20
-.10
-.00
.10
.20
.30
.40
.50
CD
SYM Config. h/b
A4PB 0.26
A4P 0.27
A4G 0.27
δ_h = -8°; δ_f = 50°

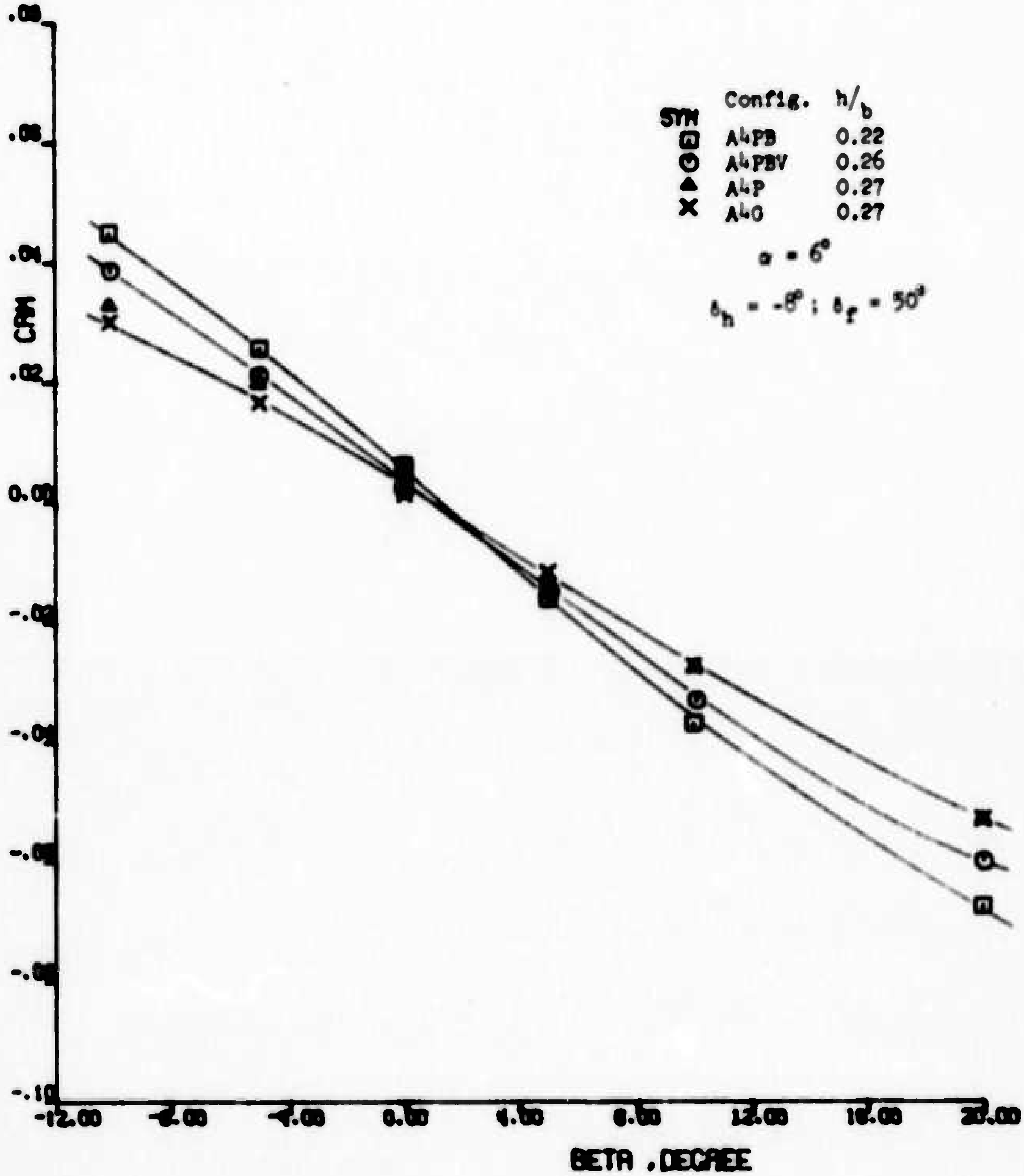


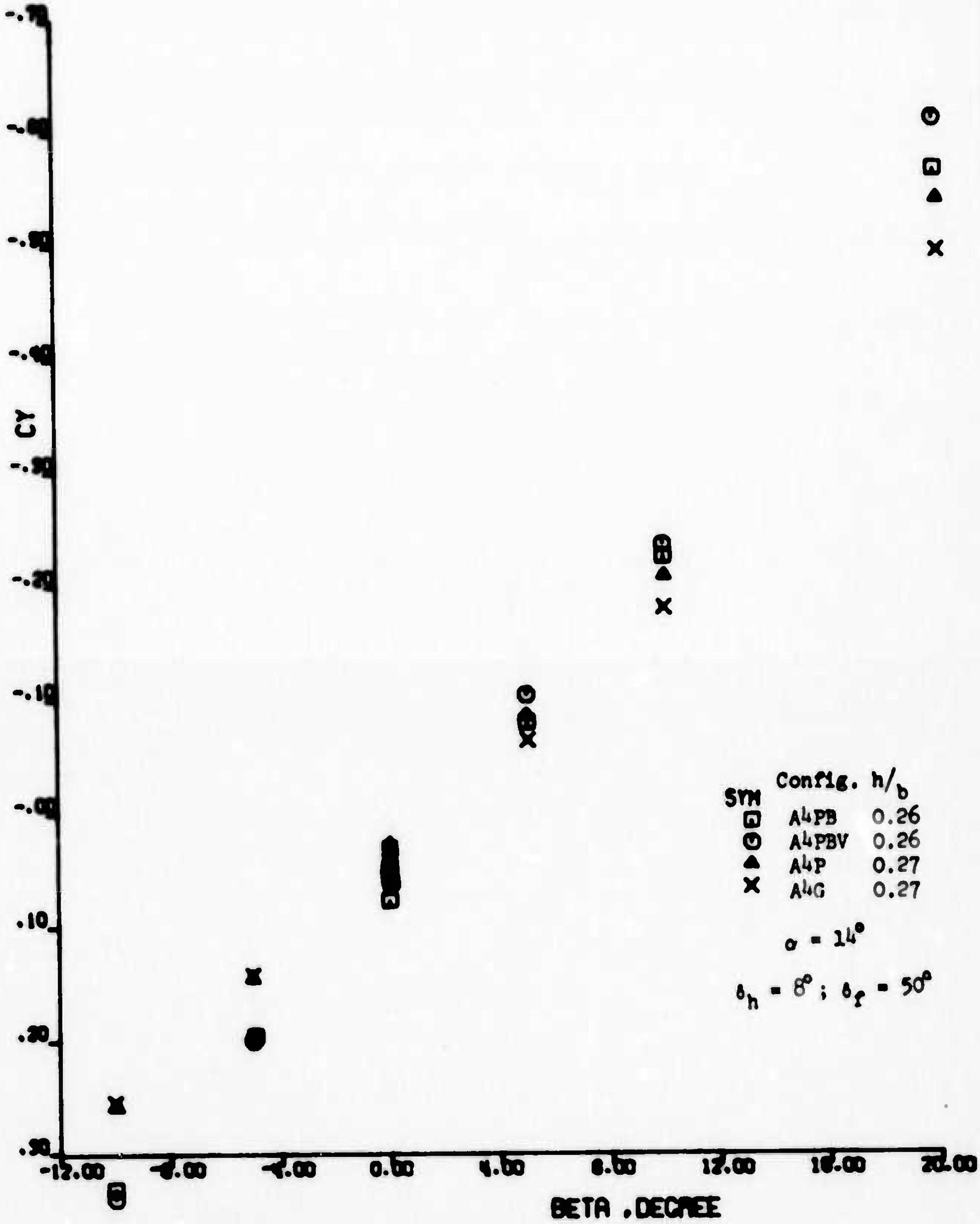
SYM Config. h/b
A4PB 0.26
A4P 0.27
A4G 0.27
δ_h = -8°; δ_f = 50°
CM
CL
.10
1.00
1.20

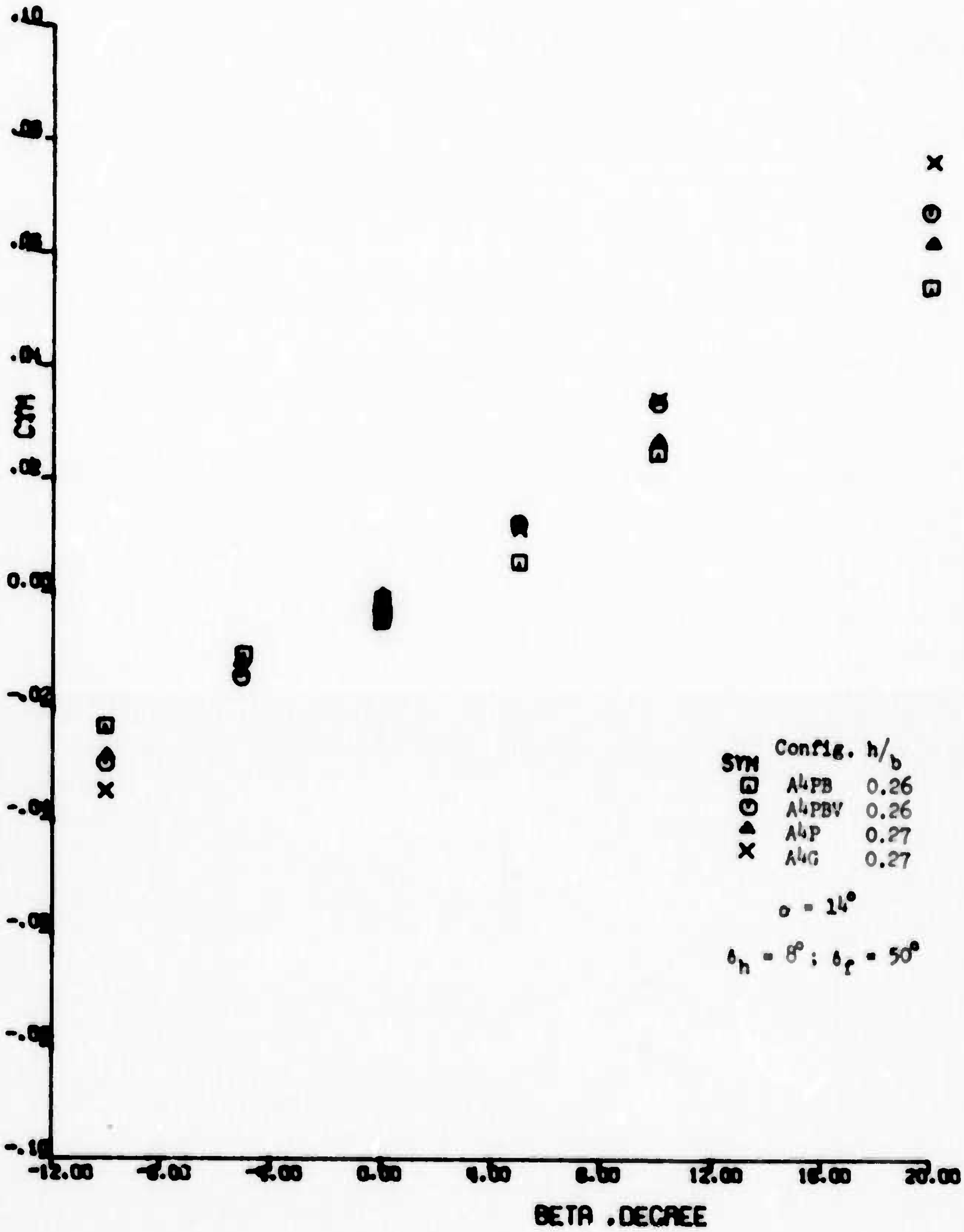


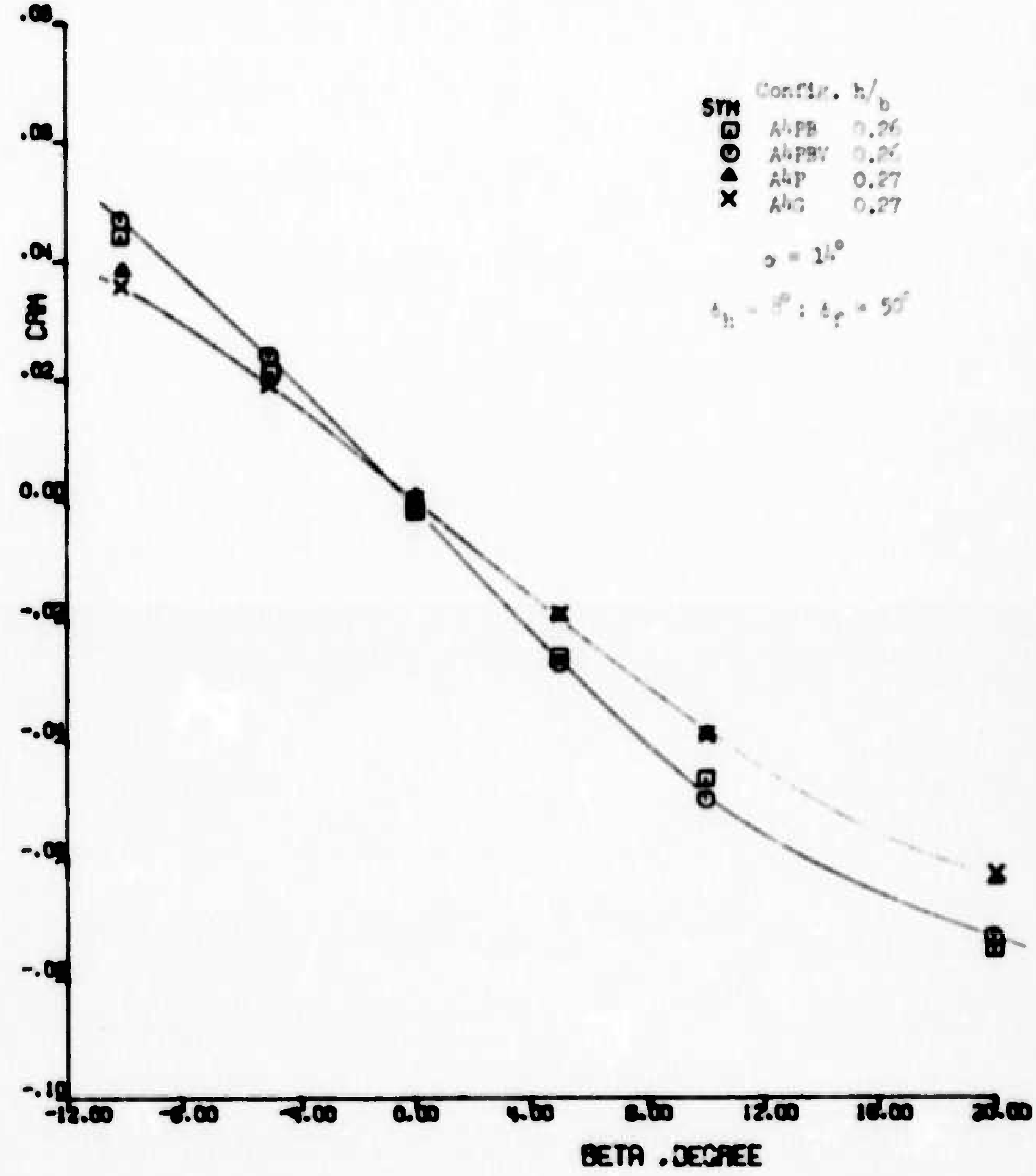
CY
BETA ,DEGREE
SYM
Config.
h/b
A4PB 0.22
A4PBV 0.26
A4P 0.27
A4G 0.27
α = 6°
δh = -8°; δr = 50°


CYM
BETA .DEGREE
SYM Config. h/b
A4PB 0.22
A4PBV 0.26
A4P 0.27
A4G 0.27
α = 6°
δh = -8° : δr = 50°

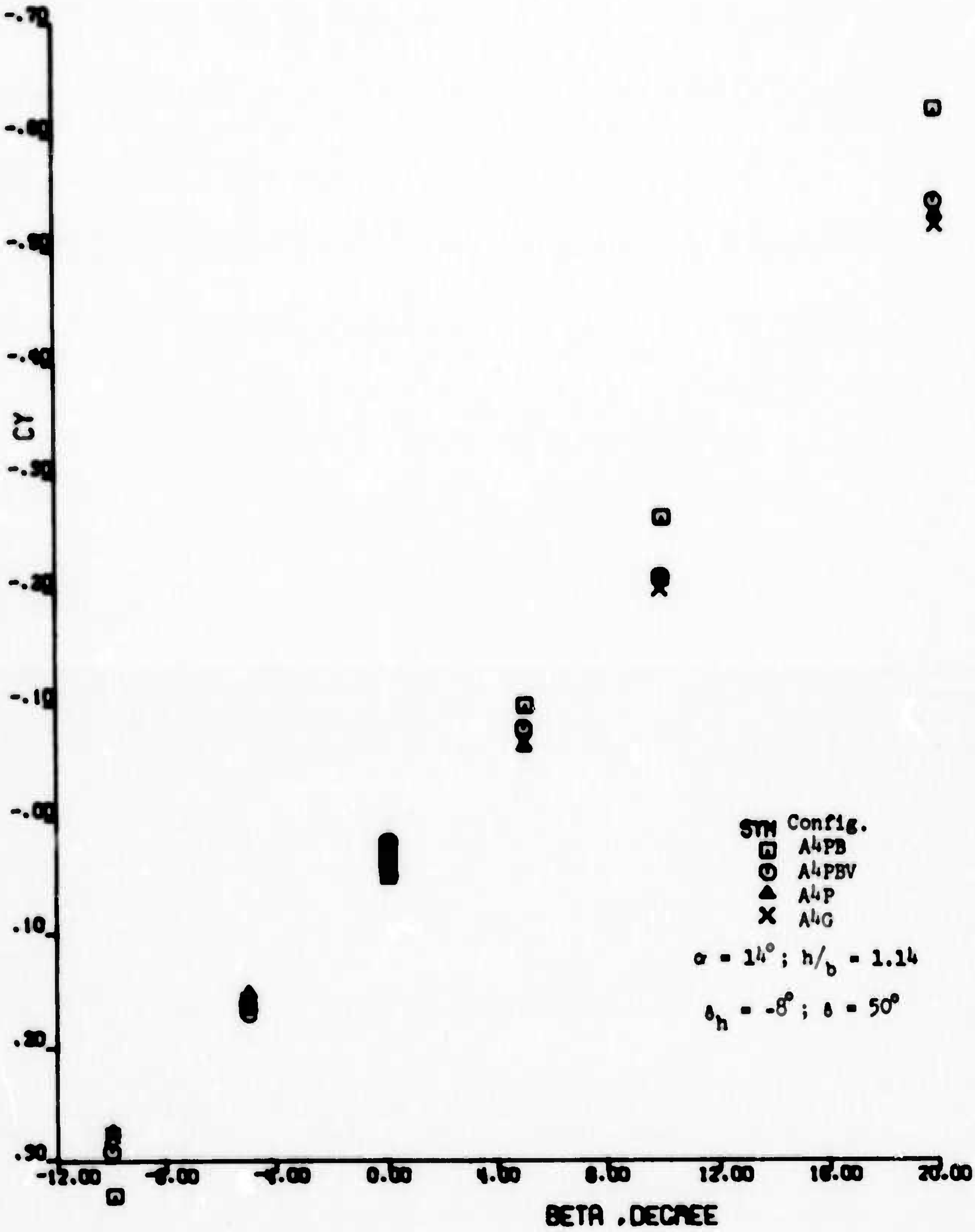

Config. h/b
SYM
A4PB 0.22
A4PBV 0.26
A4P 0.27
A4O 0.27
α = 6°
δh = -8° ; δf = 50°
CRM
BETA , DEGREE

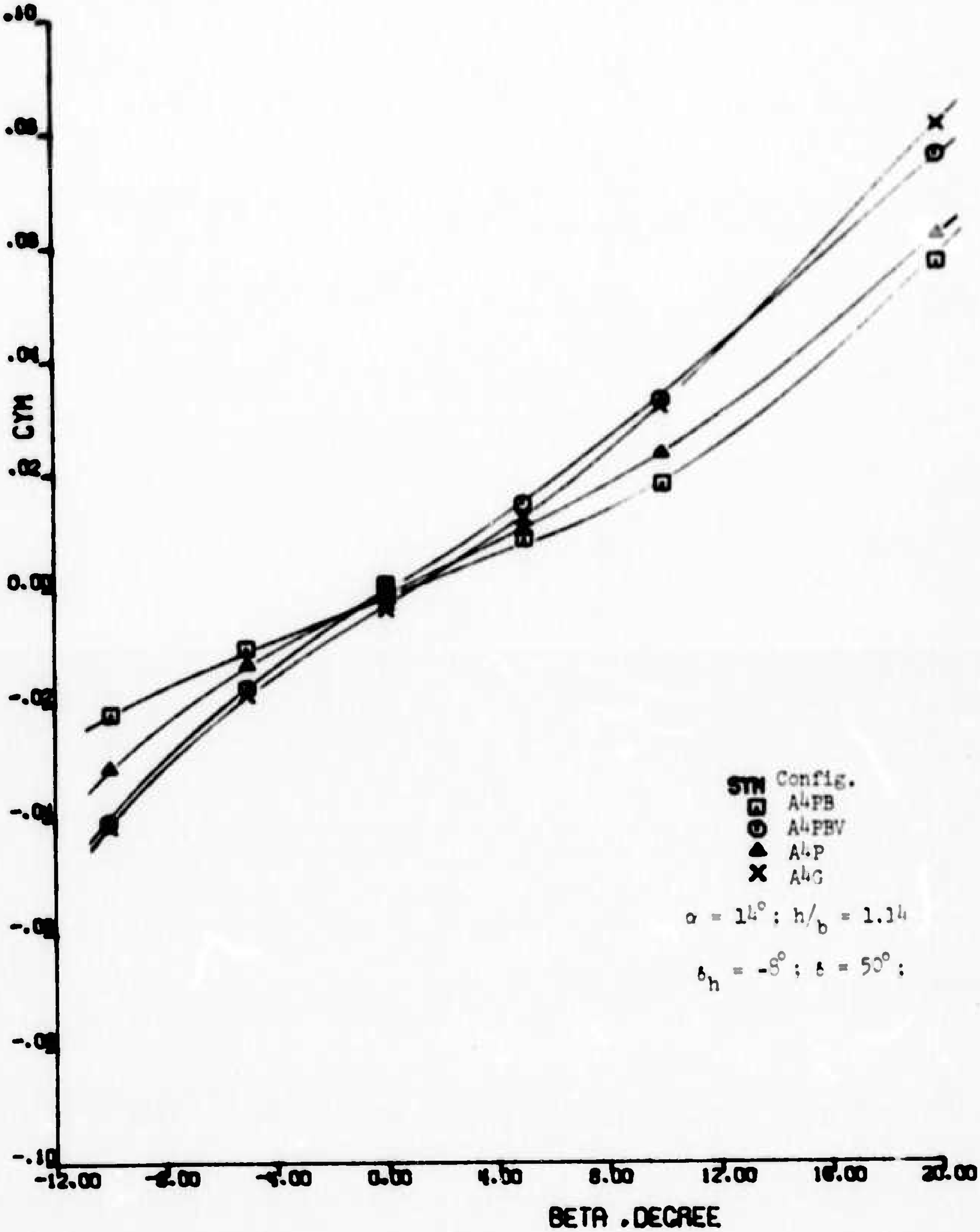

CY
-.70
-.60
-.50
-.40
-.30
-.20
-.10
-.00
.10
.20
.30
-12.00
-8.00
-4.00
0.00
4.00
8.00
12.00
16.00
20.00
BETA, DEGREE
SYM Config. h/b
A4PB 0.26
A4PBV 0.26
A4P 0.27
A4G 0.27
α = 14°
δh = 8°; δr = 50°

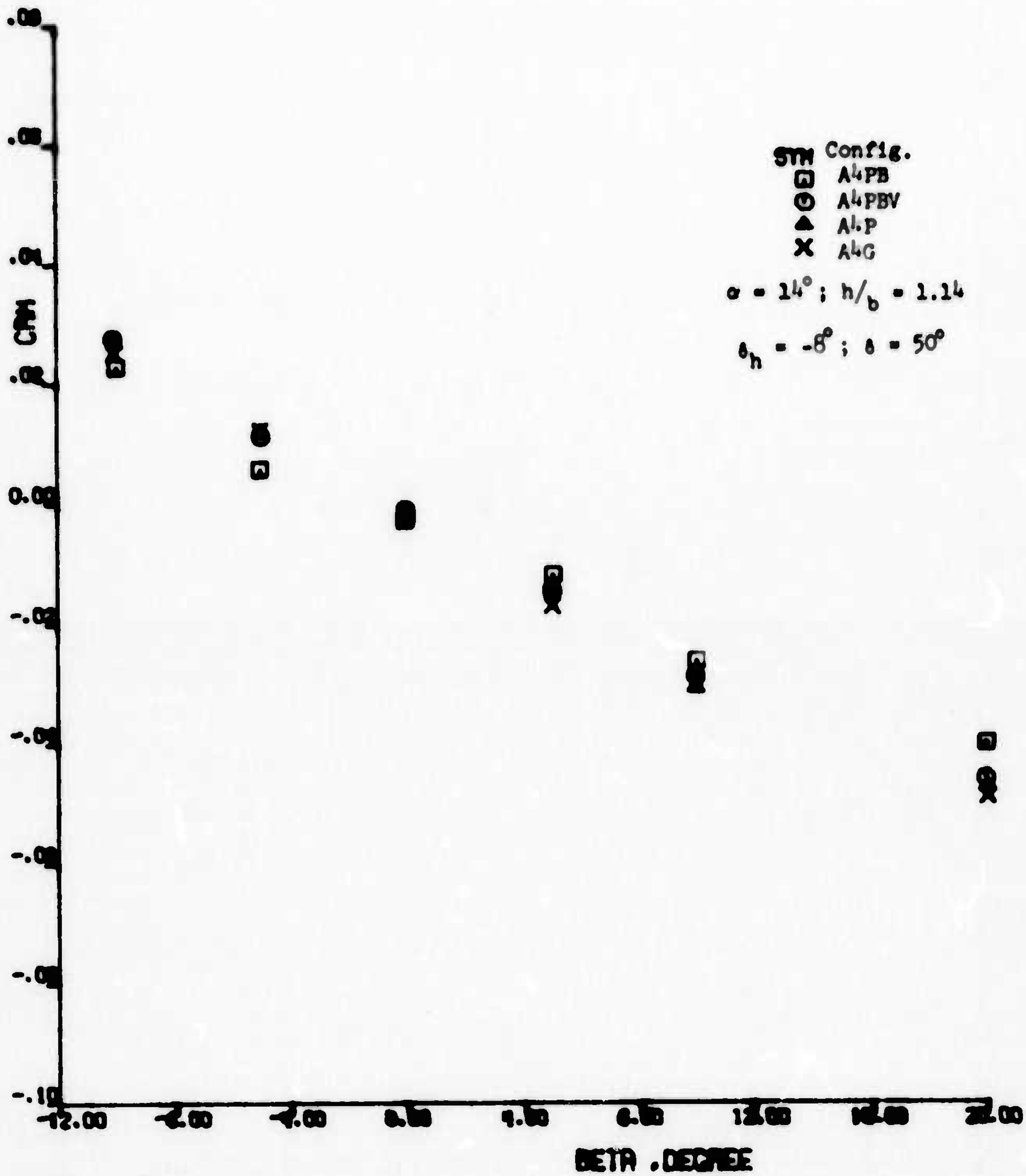

CM
-12.00
0.00
4.00
8.00
12.00
16.00
20.00
BETA ,DEGREE
SYM Config. h/b
A4PB 0.26
A4PBV 0.26
A4P 0.27
A4G 0.27
α = 14°
δh = 8°; δr = 50°



SYM
Config. h/b
A4PB 0.26
A4PBV 0.26
A4P 0.27
A4G 0.27
CRM
BETA ,DEGREE


-.70
-.60
-.50
-.40
-.30
-.20
-.10
-.00
.10
.20
.30
CY
-12.00
-8.00
-4.00
0.00
4.00
8.00
12.00
16.00
20.00
BETA ,DEGREE
STH Config.
A4PB
A4PBV
A4P
A4G
α = 14° ; h/b = 1.14
δh = -8° ; δ = 50°


CYM
BETA ,DECREE
STM Config.
A4PB
A4PBV
A4P
A4G
α = 14° ; h/b = 1.14
δh = -8° ; δ = 50° ;
-12.00
0.00
4.00
8.00
12.00
20.00
.10
0.00
-.10



STM Config.
A4PB
A4PBV
A4P
A4G
α = 14°; h/b = 1.14
δh = -8°; δ = 50°
CMM
0.00
-.10
-12.00
12.00
20.00
BETA ,DEGREE